2007/6

Documents

Statistics Norway

Statistisk sentralbyrå

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Documents

Improving the power market performance by automatic meter reading and time-differentiated pricing

Statistics Norway/Research Department/Energy and Environmental Economics

1 Abstract

In most electricity markets, households' electricity metering systems only allow prices that are fixed for long periods of time (weeks, months, years). Households can therefore not choose tariffs reflecting the continuously changing conditions and marginal costs in the electricity system. Thus, they have no incentive to adjust their electricity consumption in the short-term. This lack of demand response in the market may create inefficient allocation of resources in the short term and non-optimal investments in capacity in the long term. It may contribute to insufficient reliability of supply, higher price volatility and to an electricity system more exposed to exercise of market power. This paper discusses how automatic meter reading and direct load control technology combined with time-differentiated tariffs can increase demand response and improve the functioning of the electricity market.

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[1] Torgeir Ericson, Statistics Norway, Research Department. E-mail: toe@ssb.no. I am grateful to Bente Halvorsen for all the help and all the valuable discussions. I would also like to thank Kjetil Telle, Petter Vegard Hansen, Hanne Sæle, Annegrete Bruvoll, Torstein Bye and Knut Einar Rosendahl for their comments on earlier drafts and our discussions. I acknowledge financial support from Statistics Norway, Norwegian University of Science and Technology and Rembra AS.

1 Introduction

In most electricity markets, the electric metering system installed in households can only measure accumulated electricity consumption. Households can consequently only choose between tariffs where prices in practice are fixed for longer periods of time.[1] As these consumers do not, and can not, face the continuously varying costs of electricity consumption reflected in the wholesale prices, they have no incentives to respond to these prices by consumption adjustments. Because they do no restrict their demand if the wholesale price increases in the short-term, their retailers must bid price insensitive bids into the wholesale markets, and are thus forced to pay any price in order to serve their customers. This situation indicates a disconnection between the wholesale and the retail market; information about market conditions, communicated by the wholesale prices, is not conveyed to households. And, information about households' actual demand response and their actual willingness to pay for electricity is not reflected in the wholesale market, leading to artificially low price elasticities. [2]

This disconnection may contribute to an electricity market that performs less efficient than what is possible. When consumers face prices different from the short-term marginal cost of supply, electric generators with high costs may be utilized to cover demand during peak periods, even though many consumers would reduce their consumption if they were charged marginal costs. Furthermore, during off-peak periods, some generators are not utilized even though they may offer electricity at prices below what many consumers are willing to pay. The short-term inefficient allocation of resources may also have long-term impacts through inefficient investments in generation capacity. Low demand elasticity together with the special properties of electricity; non-storability, capacity constraints and long lead times for new expansions, may further contribute to volatile prices. This may also make it easier and more profitable to exercise market power, which exacerbates price volatility even more. Price volatility increases uncertainties regarding long-run average rate of return on capacity investments. Investors may thus be more reluctant to invest as they require higher prices to cover their risk-premium. This may in turn reduce reliability of supply and increased risk of rationing in high-demand periods. High and unpredictable prices and higher probability for shortage of supply increase the risk of political intervention in the market, which, in turn, may further reduce the propensity for investments. As this paper describes, demand response is one important factor that may contribute to a

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[1] This applies to all consumers without automatic meter reading, i.e. most of the household sector. Also consumers with "spot price" based contracts face a price that are fixed for months at a time, because they in reality only see the monthly average of the market based spot price.

[2] Demand response in this paper refers to electricity consumption adjustments to prices that vary within the day, or consumption changes as a result of incentive payments designed to induce reductions when needed, for instance during high price periods or during periods when the system is constrained.

well-functioning market with the ability of moderating volatility of prices, balancing demand and supply, and providing sufficient and timely investment in capacity.

Increased demand response may be achieved if consumers face prices that are closer to the marginal costs of supply through time-differentiated tariffs, and if they are metered automatically. Consumers will then have incentives to adjust their demand to the varying prices. Enabling technologies that can control appliances, such as direct load control of water heaters or energy management systems, may further enhance their price responsiveness. With these technologies, information about wholesale prices is conveyed to the customers, their incenctives and ability to respond to the prices increases, and information about their responses is brought back to the market. This connects the wholesale and the retail markets, and as will be described in this paper, provides for several benefits.

Many of these benefits are due to an improved electricity market performance, and are distributed among several of the participators in the market. However, the decision of whether to develop the new metering infrastructure may often hinge on individual (network) companies who may ignore benefits that are not utilized by them directly. If they find the costs too high, they may not carry out the development, even if the benefits for the society as a whole may exceed the costs. Thus, socially optimal decision on such may require governmental intervention. The discussion in this paper is exemplified using the Norwegian (and the Nordic) market. It aims to discuss benefits related to the introduction of the mentioned technologies, many of which would probably not be included in cost-benefit analysis conducted by individual companies, and many of which is not included in earlier cost-benefit evaluations in Norway (see for instance Grande and Graabak, 2004, Tjeldflåt and Vingås, 2004 and Jørum et al., 2006). Quantifying, and weighing the benefits against related costs, both for the individual companies and for the society as a whole, is however beyond the scope of this paper.

Section 2 gives a short description of the wholesale and the end-user market in Norway as a basis for the other topics addressed in this paper. Section 3 discusses the performance of the market and why many consider the deregulated market to have performed well in terms of efficient operation until now, but also why there is a potential for improvement by fully integrating the wholesale and the retail market. It discusses the reasons for the lack of short-term demand response in the electricity market, and why automatic meter reading and time-differentiated tariffs are necessary prerequisites to increase short-term demand response. Section 4 discusses implications and benefits in the market of increasing demand response, such as improved efficiency and system reliability, reduced price volatility and mitigation of exercise of market power, and, in addition, several other benefits. Section 5 reviews results from the literature describing experiments where households' responses to short-term price changes have been tested. This is important knowledge since the extent of households' demand response has implications for the benefits from demand response programs. Section 6 sums up the discussion and concludes.

2 The Norwegian electricity market

During the years of the regulated electricity market, central decision makers were responsible for maintaining reliability of supply. Risk of shortages of supply was limited since the objective of the production capacity planning was to cope with demand under nearly all circumstances (Bye and Hope, 2005). Production investment risk was low since tariffs were designed to cover the costs, and inefficient investments decisions could be recovered by tariff modifications. However, there were indications of substantial over-investment in the power sector, and a lack of cost effectiveness in the networks.[3] One of the main objectives of the deregulation was to increase efficiency and achieve a better utilization of the total resources in the power sector by leaving investment decisions to the market players (decentralised decision making). The Norwegian electricity market was deregulated in 1991. Sweden followed in 1996, and a common Norwegian and Swedish Exchange (Nord Pool) was established as the first multinational exchange for trade in power contracts in the world. Finland joined in 1998, Denmark West in 1999 and Denmark East in 2000. The Nordic countries are now connected in a common integrated electricity market. In 2005, Nord Pool Spot opened a new bidding area in the Vattenfall Europe Transmission control area in Germany (www.nordpool.com). This section presents the wholesale and the end-user market in Norway.

2.1 The wholesale market

Any producer in the Nordic area can deliver electricity to the common Nordic electricity market. The wholesale market includes power producers, power suppliers, retailers, industry and other large undertakings. In the wholesale market, the trade of electricity takes place at the Nord Pool exchange and bilaterally between different market players. About 40 percent of the physical deliveries are traded at the Nord Pool Spot (Glende et al. 2005). The exchange provides a financial market for trading contracts for price hedging and risk management, and an Elspot market for trading power contracts for next day's physical deliveries.

At the Nord Pool Elspot, the next day's hourly spot prices are settled on the basis of bids from the participators for purchase and sale (a day-ahead market). Each participant submits bids to Nord Pool

Elspot on bidding forms, and the bids are aggregated to a demand and a supply curve for each of the next day's 24 hours. The intersection of the demand and the supply curve provides the Elspot system price. The price also determines the obligations for each participant to deliver or take power from the central grid (see for instance Flatabø et al., 2003, Nord Pool, 2006a).

The determination of the spot price may lead to a power flow from one area to another that exceeds the ability of the network to transfer the electricity. If there are bottlenecks, the market is divided into pricing areas and the prices in the surplus areas are lowered and the price in the deficit area is increased, until demand and production is in balance within each area (Rønningsbak, 2000).

Because electricity cannot be economically stored, balance between production and consumption must exist at every moment. However, operational difficulties, production fall out, bottlenecks in the grid, unexpected shift in temperature or other unforeseen events may lead to differences between forecasted deliveries/demand and real deliveries/demand. Imbalance between production and consumption is the result. The Norwegian system operator (Statnett) has the responsibility of maintaining the balance in the Norwegian electricity system and provide for sufficient capacity reserves at every time. Statnett uses the Regulating Power Market to keep a stable balance and frequency in the electricity system. In this market, producers as well as consumers can bid regulating power for either up regulation or down regulation.[4]

During cold periods there is a risk that all Norwegian generating capacity is sold in the Elspot market. In order to secure sufficient power reserves for the regulating power market, a Regulating Power Option Market was established in 2000 (see Walther and Vognild, 2005, Glende et al. 2005). Here, Statnett purchases the right to utilize generating and demand resources for regulating purposes if needed. Statnett chooses the cheapest bids up to the desired amount, which then must be offered in the Regulating Power Market the next week.

2.2 The end-user market

The end-user market includes all buyers of electricity for own consumption, for instance industry, commercial buildings, households, etc. Households' electricity consumption constitutes approximately 1/3 of Norway's total electricity demand (SSB, 2006a). Approximately 60 percent of the households have standard variable contracts (in the third quarter of 2006), 11 percent have fixed price contracts,

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[3] According to Bye and Halvorsen (1999), efficiency losses in the power market, power production and distribution were considerable, and may have added up to 2.5-3 percent of GDP in 1991.

[4] Since the Nordic countries have a connected grid, regulating power anywhere in the area can treat imbalances, given there are no bottlenecks (see for instance, Wibroe et al., 2002). From 2002, the Nordic system operators created a common regulating power market in order to utilize the resources in all countries optimal.

and 29 percent have spot price based tariffs (SSB, 2006b). In the latter case, the consumers are confronted at the end of each month with the average hourly spot price, i.e. they do not face hourly varying prices. All consumers can change supplier every week. In the other Nordic countries, most end-users have fixed price contracts (Kristensen et al., 2004).

End-users in Norway with an annual consumption below 100,000 kWh have meters that measure accumulated consumption.[5] The consumers with this metering technology constitute approximately 40 percent of the total annual electricity consumption (Kolbeinstveit and Tjeldflåt, 2006). Since households on average use approximately 18,000 kWh per year (Halvorsen et al., 2005), i.e. well below the 100,000 kWh threshold, they constitute most of the consumers without automatic meter reading.[6] They are required to report their consumption a few times a year (but may report more often if they want) and are charged according to their accumulated consumption between the meter reading dates. The price these customers pay is a weighed average, over the so-called adjusted load profile from all non-hourly metered customers in the area for the relevant period.[7] Since one single customer has no significant impacts on this load profile, he or she will not receive the whole benefit if reducing consumption more than other customers do during a high price period. This means the efficient signal of hourly spot prices is substantially diluted (see also Fraser, 2001). The result is that at what time between the meter reading dates that the consumer uses electricity, does not matter for the total bill. The incentive is thus only to save energy for the whole period, independent on the time of day/week/month this saving is carried out. Note that this also applies to those with spot price based tariffs who only face the average of the hourly spot prices.

3 Potential for improvement in the electricity market

In general, the Nordic market has so far been working well (Flatabø et al., 2003, Bergman, 2005, von der Fehr et al., 2005). For instance, the deregulation have yielded a downward pressure on the electricity price as excess capacity has been exposed to competition in the market, and, prices between customer groups have equalized (Bye and Hope, 2005). Tjeldflåt (2005) considers the end-user market to function quite well, since customers seem to change retailer when the price differential between retailers is high, and because the market share of the dominating retailers has declined recent years.

[5] From 1 January 2005, all customers with an annual consumption above 100,000 kWh were required to have hourly metering of consumption.

[6] The households may require automatic meter reading but they must pay for it themselves, though with a maximum price.

[7] Consumers with fixed price contracts pay only according to their accumulated consumption.

Also, according to Statnett (2004), Norway has one of the most efficient and best utilized transmission systems for electricity in the world.

3.1 The disconnected wholesale and retail electricity markets

Increased integration between the retail and the wholesale market may improve the functioning of the market further. Figure 3.1 illustrates the existing situation in which most households now have no incentives to respond to short-term changes in wholesale prices by consumption adjustments. It shows the hourly spot prices in the Oslo pricing area during the winter 2002/2003, along with the prices offered through a standard variable contract from one of the larger suppliers in the Oslo region.

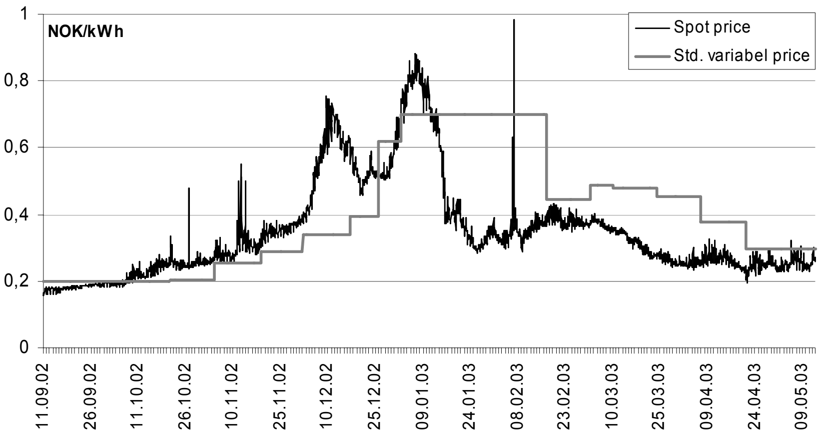

Figure 3.1. Hourly spot prices (in the Oslo region) and the price offered from a supplier through a standard variable price contract in the winter 2002/2003.

As seen in the figure, the spot price rose to very high levels in December 2002 and the beginning of January 2003, due to a situation with scarcity of energy.[8] The standard price facing the customers, however, was in parts of this period lower, sometimes only about half of the market price. Furthermore, from mid-January until May, the customer price was high above the market price, sometimes more than twice. We can see here that the standard price did not bring the energy scarcity price signal to the customers at the time the market considered the situation to be constrained. Neither did the standard price signal inform the customers when the market considered this situation to be over. Also important is the price spike 6 February 2003, where the peak price signalled a power shortage situation (see also Figure 3.3). The figure illustrates that consumers have little incentive to

[8] More on the 2002/03 winter can be found in for instance Bye et al. (2003b), Nordel (2003), Finon et al. (2004), von der Fehr et al. (2005), OED (2003).

adjust consumption according to short-term changing market prices.[9] Because of this, their retailers must bid price insensitive bids into the wholesale markets, and are forced to pay any price in order to serve their customers. This is illustrated in Figure 3.2.

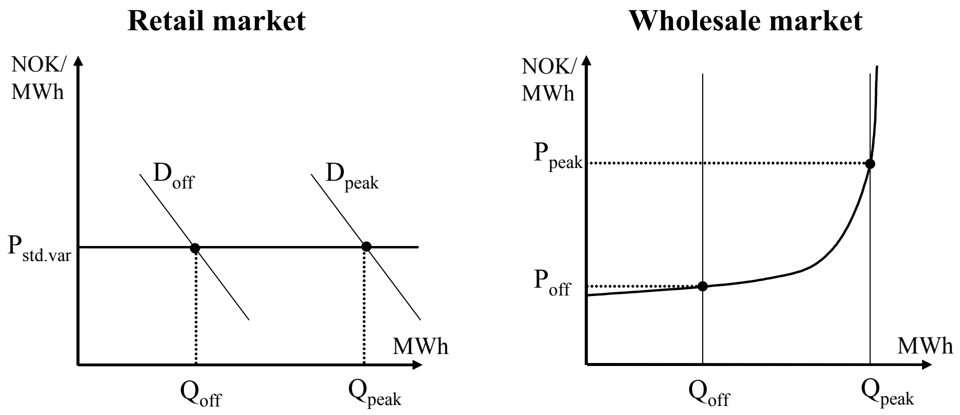

Figure 3.2. The disconnection between the wholesale and the retail markets.

The left figure illustrates consumers' demand curves in off-peak and peak periods of the day (D_{off} and D_{peak}), and a standard variable price ($P_{std,var}$) offered by their retailer, which can not change in any of the periods. The elastic demand curves indicate that consumers are price responsive and willing to adjust consumption on a short notice if they were given this opportunity (the assumption that consumers are price responsive is supported in the review in Section 5). However, their price does not change in the short-term. Consequently, their demand appears inelastic in the wholesale market both in the off-peak as well as in the peak periods. The figure to the right illustrates this with two perfectly inelastic demand curves (assuming all customers are completely inelastic).

This situation indicates a disconnection between the wholesale and the retail market; information about short-term changing market conditions is not received by consumers. And, information about consumers' actual demand response and their willingness to pay for electricity is not reflected in their demand curves in the wholesale market.

The actual demand curves at the Nord Pool are however not as inelastic as they appear in Figure 3.2, because some customers with automatic meter reading and time-differentiated tariffs also are present in the wholesale market. However, Figure 3.3, showing the purchase and sales curves at Nord

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[9] We know that tacit collusion between consumers may give some market response, thus changing the load profile and costs for the consumers, while each consumer alone will not have this impact. However, it is questionable whether consumers will act like this, for instance due to lack of knowledge regarding the load profiling effects and due to free rider problems from consumers benefiting from others tacit collusive behaviour.

Pool Spot the 6 February 2003, hour 17:00-18:00, illustrates that the short-term price response still may be limited, as the purchase curve is nearly vertical at higher prices. [10]

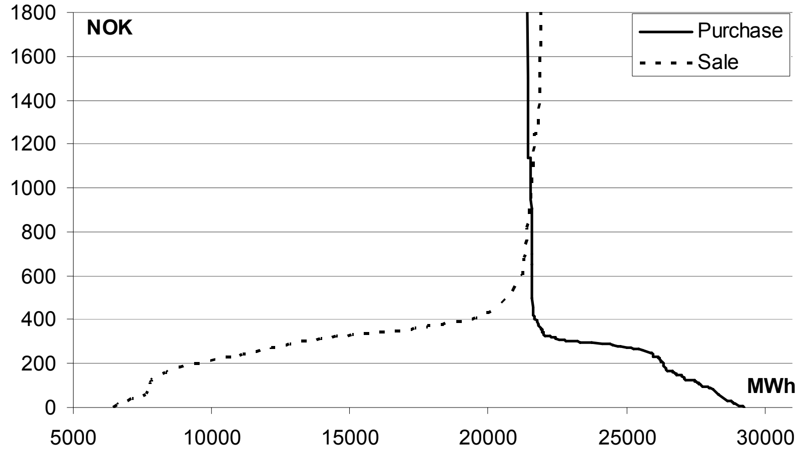

Figure 3.3. Elspot purchase/sales curves. Hour 17:00-18:00, 6. February 2003, System Price NOK 981,14. (Source: Nord Pool Spot AS)

That the demand response is low, is further supported in, for instance, Hansen and Bye (2006) who estimated low short-term demand elasticities in a simultaneous multimarket model for the Norwegian and the Swedish market. They found the price elasticity to be approximately -0.015 in Norway and even smaller in Sweden.[11]

The low elasticity may be a consequence of a too small amount of consumption with contracts tied to the spot price, and which also are hourly metered. It may also reflect low responses among those customers. For instance, the share of the Norwegian electricity consumption in the energy-intensive manufacturing and pulp and paper industry with contracts tied to the spot price constitute only approximately 0.2 % (SSB, 2006a, 2006b). For mining, quarrying and other manufacturing industries this number is approximately 2.6 %. These sectors constitute about 45 % of the total Norwegian annual electricity consumption. In addition, households and others without automatic meter reading constitute around 40 % of the annual consumption.

Thus, the part of the Norwegian consumption on contracts tied to the spot price probably constitutes less than 20 %. Furthermore, some of this consumption probably only faces monthly average spot prices. This means that the main part of the Norwegian consumption today has no

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[10] Note that the threshold for requirement of automatic meter reading was lowered from 400,000 kWh to 100,000 kWh in 2005. This increased the amount of the Norwegian annual consumption on this metering technology from 50% to 60% (Tjeldflåt and Vingås, 2004). The elasticity may therefore be somewhat higher in today's market than what this figure illustrates.

incentives to be short-term responsive. Given the many long-term contracts in the other Nordic countries, the share of the total Nordic consumption (approximately 400 TWh) with hourly spot price contracts is thus probably only a few percent.

A high share of the Norwegian consumption tied to spot price contracts is within the consumer group called “Other industry”, i.e. for instance, trade, hotels and restaurants, public administration, education, health and social work and other service activities. The elasticity for this group of customers will therefore be important for the total response in the Norwegian (and Nordic) market. This group’s price elasticity is not known, but, according to Faruqui and George (2002) price elasticities for small to medium size commercial and industrial consumers are significantly smaller than for residential consumers, suggesting households could be important contributors to increase demand response in the market.

As mentioned, approximately 40 % of the annual consumption in Norway, with households as the largest share, can only choose tariffs with prices that do not reflect the short-term marginal cost of supply. Given that all households on spot price based contracts today (approximately 29 % of the households), continue on hourly spot price contracts if they are provided with automatic meter reading, the share of the Norwegian annual consumption with incentives to be short-term demand responsive could increase by probably 50 % from today’s level.

Furthermore, these consumers’ electricity consumption is likely to constitute a larger share than 40 % during cold periods due to their high temperature sensitivity (compared with for instance large industry). This means that a significant share of the market has no possibility to be responsive to prices in periods when demand response often is needed most.

3.2 Connecting the markets and increasing demand response with automatic meter reading and time-differentiated tariffs

The previous discussion indicates that there may be a considerable contribution to increased demand response by letting the customers without automatic meter reading to be fully integrated in the wholesale market. One way to achieve this is to provide customers with automatic meter reading so that they can choose electricity tariffs reflecting wholesale price variations. Furthermore, installation of notification systems able to signal the current price level on displays or by signal lamps, and possibilities for direct control of loads, may also increase consumers’ demand response.

[11] The elasticity may be somewhat higher now for the same reason as in the previous footnote.

With such equipment installed, retailers can offer a range of new tariffs and products to the electricity customers.[12] For instance, a *spot price* contract may be popular among customers with a high risk tolerance who does not want to pay the "price insurance premium" related to for instance a fixed price contract.[13] Customers with spot price contracts can expect a lower electricity bill than with a fixed price contract (Faruqui et al., 2002). Besides, if they can control and reduce their electricity consumption in peak hours, they may provide themselves with physical risk insurance towards the price volatility by being demand responsive (Hirst, 2002b).

In between the pure spot price contract, where most of the risk is placed on the consumer, and the fixed price contract where the main risk is placed on the supplier, there may emerge a variety of new kinds of contracts that fit different customers' tolerance for risk and ability to respond to time-differentiation in price. An example is the *time-of-use tariff* (TOU), which has prices that vary by blocks of time within the day, but are fixed and known by customers in advance independently of the conditions in the electricity system (see for instance Faruqui and George, 2002). This tariff is however quite static. If the system is unconstrained, the TOU peak price may be much higher than the wholesale price, and if the system is constrained, a higher price than the TOU peak price may be needed to signal the market condition and wholesale prices. A more dynamic tariff, able to reflect the spot price and the conditions in the electricity system more accurately, is the *critical-peak pricing* (CPP). This tariff can increase the peak price if the system is severely constrained, and is thus a hybrid between the TOU and the spot price tariff. The TOU and the CPP tariffs are more predictable for the consumers than the hourly spot price at the same time as they provide incentives for consumption adjustments. The CPP rate lessens the price and quantity risk for the retailer compared with the TOU rate because of the possibility to impose a critical peak price during special circumstances.

Another interesting tariff is a *two-part real-time pricing* (RTP) contract. This tariff offers consumers a fixed price for an agreed volume and the spot price for deviations from this volume. If the consumer uses less than what is agreed on, the consumer will be paid back the spot price for the deviation. If the consumer uses more, he pays the spot price for the deviation. Other versions of this tariff may also price the deviation somewhere between the fixed price and the spot price (see for

[12] See also Mauldin, 1997, Eakin and Faruqui, 2000, Long et al., 2000, Camfield et al., 2002, Irastorza, 2005.

[13] A *fixed price* contract ensures a known price a year or more in advance and protects customers from possible volatile prices in the wholesale market and reduces the risk for unforeseen expenditures during the contract period. However, offering a fixed price contract exposes the retailer for price and quantity risk, as procurement costs at the wholesale market and the customers' consumption level is unknown. Thus, the retailer charges more than the expected average wholesale price for the contract period to account for this uncertainty, or hedges at the financial market through for instance forward contracts. See for instance, Hirst, 2002b, Gersten, 1999, Woo et al., 2004, Nord Pool, 2006b, Deng and Oren, 2006.

instance Braithwait and Eakin, 2002, Horowitz and Woo, 2006 or Hunt, 2002).[14] Consumers may also be offered a *spot price contract with a cap* at some level agreed on by the retailer and customer.

Both retailers and customers expose themselves for financial risk dependent on the electricity contract agreed on (Sioshansi, 2002, Solem et al., 2003a). Figure 3.4 summarizes some different tariffs and how they share risk between customer and retailer.

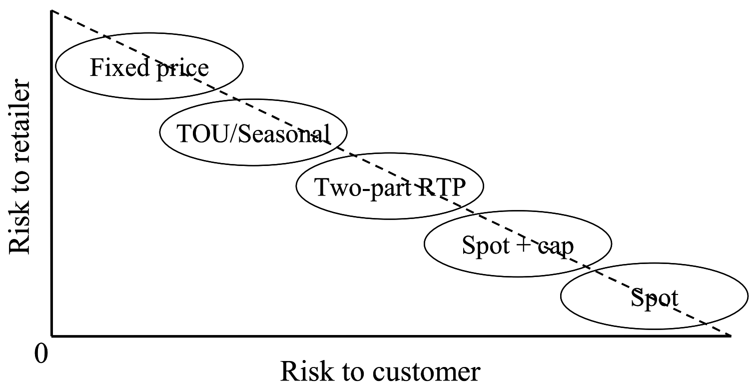

Figure 3.4. Electricity tariffs with differing risk on the customer or retailer. (Adapted from Eakin and Faruqui, 2000).

Due to differing risk taking preferences among the customers, they are likely to diversify to the different tariffs. The retailer can hedge some of its risk at the financial markets, thereby contributing to more predictable prices also for producers.

In addition, retailers may offer *direct load control* of appliances in order to assist end-users' price response, as a mean of attracting customers. Agreements can be made where load control is carried out at some predefined price levels, power consumption levels or in predefined periods in combination with any of the above mentioned contracts, to reduce or shift consumption when desired (see for instance Solem et al., 2003a,b).

When wholesale prices are conveyed to the customers and they adjust consumption to the varying prices, their retailers will bid price sensitive bids into the wholesale market. The two disconnected markets are then integrated.

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[14] Trondheim Energiverk in Norway is currently offering a version of a two part RTP tariff to residential customers, see www.tev.no.

4 Benefits from increased demand response

There are a number of benefits that may be released with time-differentiated pricing, automatic meter reading and direct load control. This section discusses the following; improved economic efficiency in the electricity market, increased system reliability, reduced price volatility, mitigation of market power, and other benefits.

4.1 Improved economic efficiency in the electricity market

A market is most efficient when customers pay the marginal cost and make consumption decisions based on their marginal valuation of the commodity. For the electricity market, this means that consumers pay the wholesale hourly spot prices for their hourly consumption. The inefficiencies in the disconnection of the wholesale and the end-user markets, arise when customer prices deviate from the wholesale prices. When customers pay less than the market price during peak periods, production technologies with high costs may be used to cover demand, even though many consumers would not find it worthwhile to consume electricity if they had been charged the marginal cost of this supply (see also Amundsen et al., 1996, Lafferty et al., 2001, Borenstein, 2002b, DOE, 2006). When customers pay more than the market price during off-peak periods, generators are not utilized even though many consumers would find the electricity production worth the costs.

Figure 4.1 illustrates demand and supply curves for two different periods of the day; one peak and one off-peak period, in an electricity market where the customers are metered hourly and charged wholesale prices.

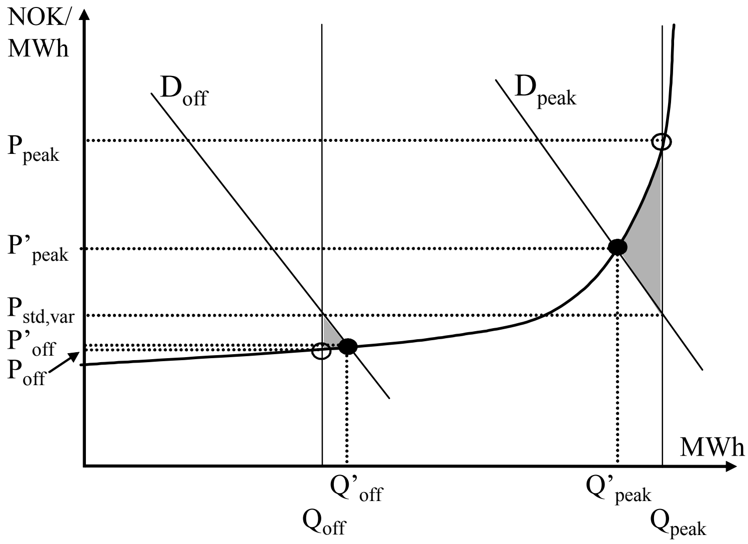

Figure 4.1. A connected market with demand responsive consumers with time-differentiated tariffs.

The figure describes a connected market, as opposed to the situation in Section 3.1. Customers are confronted with the prices in the wholesale market and make consumption decisions according to their willingness to pay. Because the information about the customers' demand responsiveness is brought to the wholesale market, their demand curves will no longer appear vertical as is also shown in the figure. The market therefore clears at other consumption and price levels than before. During a high demand period, this occurs at a lower consumption and price level (Q'_{peak},P'_{peak}), than in the situation with no demand response (Q_{peak},P_{peak}). During a low demand period, the market clears at (Q'_{off},P'_{off}), i.e. at a higher consumption and price level than in the situation with no demand response (Q_{off},P_{off}). The efficiency gains that arise when customers face marginal prices rather than fixed prices are illustrated in the figure as the shaded areas (for two different periods of the day).[15]

As seen in Figure 3.1, there is almost always a divergence between the customer price and the wholesale price. In a tightening Norwegian and Nordic electricity market, where prices may fluctuate more, efficiency gains from time-differentiated tariffs and increased short-term demand response from households may thus have an increasing potential.

[15] The standard variable tariff and the spot price based tariff are able to bring the customer price closer to the wholesale price than a fixed price contract for a year is. However, in today's market, the wholesale prices may rise without the prices in these contracts following closely. The deviation between customer price and wholesale price may thus be substantial, also for these contract types, as was described in Section 3.1 (see Figure 3.1). Furthermore, none of these contracts have the possibility to reflect short-term price spikes as the one exemplified 6 February 2003.

4.2 Increased system reliability

Reliability of supply in the power system is often characterised by system adequacy and security. Adequacy relates to the ability of the system to provide consumers' demand at all times, while security relates to the ability of the system to handle disturbances (Oren, 2005). The Norwegian electricity market organisation is often referred to as an energy-only market, which means that generators are paid only for their produced energy.[16] Under ideal conditions, energy-only markets are claimed to provide an adequate level of supply (Eltra et al., 2002, Oren, 2005). This level is where the cost of new capacity equals the willingness to pay for such capacity (von der Fehr et al., 2005).

However, there are concerns regarding the energy-only market's ability to provide sufficient investments.[17] It is argued that the markets may suffer from inadequate capacity levels due to a number of conditions which may contribute to inefficient market performance. As Morey (2001) puts it, the question seems not to be whether a competitive market can provide adequate capacity, but whether a competitive wholesale power market can be achieved. One of the conditions that may contribute to inefficient market performance is lack of demand response.

One of the reasons for this is that in the deregulated energy-only market framework, investments in generators (and demand side measures) are based on expectations of future energy prices (and maybe on income from the Regulating Power Market and Regulating Power Option Market). This means that the market model relies heavily on price signals, and consequently that the economic integrity of pricing mechanisms within the market rules is paramount (Fraser, 2001). Prices should provide the correct incentives for long-term investments decision and signal how much total capacity, and which type of capacity, to build. However, when wholesale prices are not seen by the customers and their actual willingness to pay for supply of electricity is not reflected in the price in the market, the level of investments may consequently deviate from the most efficient one. Stoft (2003) argues that markets lacking demand responsiveness to prices learn nothing from high prices about consumer preferences for reliability. The required information simply does not exist when consumers' trade off between consuming and not consuming at different price levels is not revealed in the market.

Furthermore, because of the inelasticity of consumers and because it is impossible to prevent any customers from consuming electricity when they want, there is a chance that the demand and supply curve may fail to intersect (see Stoft, 2002, calling this a result of the two "Demand-Side Flaws": lack

[16] This is because no additional capacity mechanisms to ensure sufficient generation capacity exist. However, there may be payment for other services also, such as the Regulating Power Market or the Regulating Power Option Market. It may therefore not be entirely correct to refer to the Norwegian market as an energy-only market (Botterud and Korpås, 2004).

[17] See, for instance, Doorman, 2000, Agerholm et al., 2004, Botterud and Korpås, 2006, de Vries, 2003, 2004, Stoft, 2002, 2003, Eltra et al., 2002, Vázquez et al., 2002, Nordel, 2002.

of metering and real-time billing, and, lack of real-time control of power flow to specific customers). Any actions directed towards reducing the probability of disruptions of supply will, according to Jaffe and Felder (1996), create positive externalities. They argue that resource adequacy is a public good and will be underprovided in the market. Others argue that uncertainties deteriorate the willingness to invest. For instance, Agerholm et al. (2004) point out uncertainties about the price of electricity, and whether price caps or other changes to the market framework might be imposed by regulators.[18] Stoft (2003) mentions the business risk associated with high price volatility as another factor. The long-run average rate of return is difficult to predict, so investors want a higher risk-premium on these risky investments. According to de Vries and Hakvoort (2004), it is not unlikely that investors will choose a risk-averse strategy, taken into account many of these (unquantifiable) uncertainties. Doorman (2000) argues that uncertainty is especially harmful for peaking generators, since the generator with the highest marginal cost will have to cover its investment during a few short periods where all generators run at their capacity limits. Given risk-aversion among investors, investments may thus only occur when very high prices can be expected, and if there are no risks of price caps (see also Vázquez et al., 2002). However, as discussed in Finon et al. (2004), while high prices may be necessary to trigger investment, politicians may find them unacceptable. For instance, during the high-price period in 2002/03 politicians threatened to reregulate the Norwegian market (Bye and Hope, 2005). Politicians may especially find high prices unacceptable if they suspect high prices to be a result of abuse of market power by companies that are taking advantage of insufficient demand response (Oren, 2005, see also Section 4.4). And, if there is a risk that politicians may intervene in the price formation, investments may be postponed (Nordel, 2004a).

The above discussion indicates several conditions that may cause the investment level to deviate from the most efficient one. Whether this is the situation in Norway will not be evaluated here. However, as illustrated by Glende et al. (2005), we note that the peak load in Norway has been steadily increasing the last years, while the generating capacity has not increased to the same extent, resulting in a gradually deteriorating capacity balance. Others, for instance Bye and Hope (2005),

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[18] Agerholm et al. (2004) also mention conditions which not necessarily are related to lack of demand response, for instance uncertainties about prices of other fuels and whether environmental restrictions (CO_2 targets and prices), taxes or other changes to the framework might be imposed by regulators. It has also been maintained that the electricity market does not perform efficiently if entry barriers are high enough to prevent investments by new entrants. Incumbent producers may exploit this by under-investing in capacity in order to raise prices (Vázquez et al., 2002, Eltra et al., 2002). High entry barriers may be the case in the Nordic countries since, according to for instance Bye et al. (2003a) and TU (2006), public regulations here make it very difficult to establish new capacity. Furthermore, according to for instance Nordel (2004b), one of the prerequisites for the market to work is that risk can be kept at a reasonable level. Risk may be overcome by hedging at the financial markets (Stoft, 2003). However, financial contracts at Nord Pool can not be purchased for more than four years ahead which may not be sufficient for investment hedging purposes given long lead times and life times of generators. Furthermore, existing standard financial instruments are based on a flat profile which means e.g. peaking units possibly may lack a hedging product that otherwise, according to Nordel (2004b), could have secured more predictable revenues during peak periods.

Grande et al. (2001) and von der Fehr et al. (2005), have also emphasized the tighter market conditions that now may be seen, and that ensuring adequate capacity is an important challenge. Statnett (2006b) points out that the power sector in Norway has never before been on the way into an investment phase with the organization of the sector that we have today, which confronts the sector with new challenges. Statnett asserts that within the sector organization and the policy we have today, it is not likely that new overcapacity will systematically be built; a situation with little or scarce capacity will be persistent.

Some forecasts of the power balance in Norway and the whole Nordel area may further illustrate this. For the previous winter (2005/06), Norway as well as the whole Nordel area (the Nordic countries), were forecasted to have a deficit in the power balance in a very cold winter day, so that import to maintain balance between demand and supply could have been necessary (Statnett, 2005a, Nordel, 2005c). For the present winter (2006/07), both Norway and the Nordel area are forecasted to have a surplus in the power balance (Statnett, 2006a, Nordel, 2006b). Forecasts for the 2008/09 winter again indicates the need for import in case of a very cold winter day for Norway and the whole Nordel area, while the situation in 2009/10 indicates surplus for Norway but a deficit in the power balance for the Nordel area (Nordel, 2005a, 2006a). These forecasts indicate that the demand and supply levels the next years will alternate around what may be regarded as a tighter balance.

Hunt (2002) and Fraser (2001) maintain that the lack of demand response is the reason for the worries about reliability and the need for capacity markets, installed capacity requirements, price caps and other holdovers from the period of regulation, seen in many countries.[19] Demand response is an important factor that may improve the functioning of the market and mitigate many of the concerns discussed above. One of the consequences with inelastic demand accompanied by increasing peak power consumption and lack of investments in supply, is that failure of market clearing in the day-ahead as well as in the regulating market may occur (Stridbæk, 2003). This is illustrated in Figure 4.2.

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[19] Due to the concerns of the inability of the energy-only market to ensure adequate supply levels, additional instruments and different organizations of the market have been proposed and are in use in different markets around the world in order to meet the shortcomings of the energy-only market or in order to make the markets more complete. Capacity obligations, capacity payments, proxy market pricing or capacity subscription (see a discussion of these in Doorman, 2000), consumer response options (Stridbæk, 2003), and reliability contracts based on financial call options (Vázquez et al., 2002) are some examples.

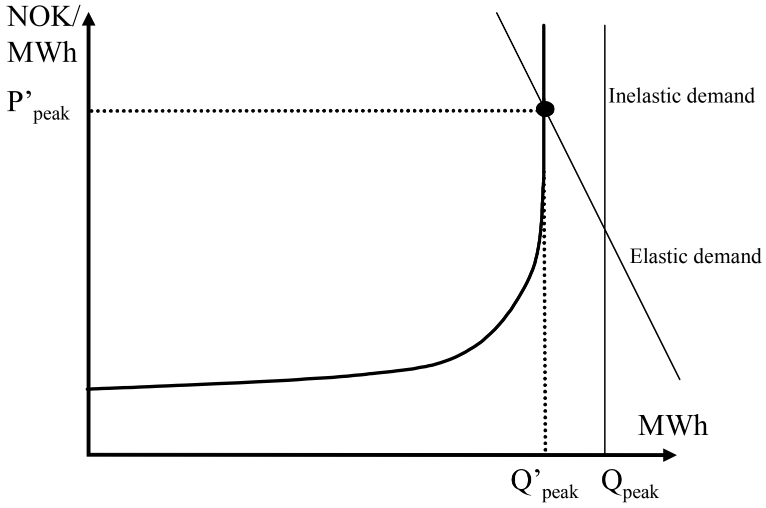

Figure 4.2. Demand response may avoid rationing

The figure indicates two different situations. The first is where inelastic demand (Q_{peak}) exceeds available capacity (Q'_{peak}), for instance due to extreme cold, generator outages etc. With inelastic demand, involuntary disconnection of customers with the amount of Q_{peak}- Q'_{peak} may be necessary to maintain the power balance. This may lead to substantial loss of load costs, and may also be considered socially unacceptable. In addition, physical rationing is inefficient since all disconnected customers are equally affected, regardless of their willingness to pay for the electricity (Faruqui et al., 2002). [20]

Instead of resorting to involuntary rationing, this situation can therefore be managed by voluntary adjustments to high prices, as indicated in the second situation where demand response is present in the wholesale market with an elastic demand curve. Demand response ensures market clearing at Q'_{peak}, and thus helps balancing demand and supply. This implies that periods of under-investments of capacity in the market leads to higher prices rather than rationing of customers. As Fraser (2001) explains, if customers' willingness to pay is brought through to the wholesale market, each customer actually declares a maximum reservation price (i.e., each customer's value of lost load), which the customer is prepared to pay. The demand curve then becomes an ordered list of individual customer value of lost loads. Some argue that when customers ration themselves in this way, the public good characteristic of system adequacy is turned into a private one (IEA, 2003, Oren, 2005). The second

[20] The average interruption cost for the total of Norwegian consumption is estimated at about 4 €/kWh interrupted (Glende et al., 2005). Typically average outage cost used for system planning purposes in the US, range from $2.5 to $5/kWh (Boisvert et al., 2002, DOE, 2006).

situation also illustrates that the elastic demand curve may ensure clearing above marginal cost of the last unit, which is necessary for generators to cover their fixed costs (see for instance Fraser, 2001 or Stoft, 2002).

According to Hunt (2002), California had to employ rolling blackouts with a shortage of only 300 MW in a system of 50,000 MW, which means that a very small reduction in demand was needed to avoid the blackouts. Others have also pointed out that one of the key factors of the problems in California's market was the absence of demand response (Faruqui and George, 2002, Fraser, 2001).

Increased demand response provides flatter daily load shapes, and a better utilization of the capacity for both generators and the networks. With lower peaks, the transmission or generator capacity may not need to be dimensioned for the same extreme demand that may only occur for a few hours a year. The necessity of expanding the transmission system or building new peak power plants may thus be less, or deferred (Borenstein, 2002b, DOE, 2006, Earle and Faruqui, 2006).

Another advantage with demand responsive customers is that their bidding in the day-ahead market implies that demand during extreme situations is less than without demand response (see Figure 4.1). This may have reliability benefits since additional supplies become available for the Regulating Power Market to meet possible contingencies (see also Hirst, 2002a, Braithwait and Eakin, 2002). Some of these resources may be better suited for fast response in this market. Opportunities for retailers or network companies to aggregate reductions from certain types of load and sell this into the Regulating Power Market may also provide the system operator with more competition and cheaper prices in this balancing market (see Grande et al., 2000). Furthermore, as Braithwait and Eakin (2002) maintain, when the market performance is improved and load becomes more stable, the desired or needed reserve requirement may decrease.

It may also be less expensive and less time consuming to activate demand response and strengthen the peak load balance compared to investment in generating capacity (Earle and Faruqui, 2006, Nordel 2004a). Furthermore, Earle and Faruqui argue how implementing the necessary infrastructure for demand response, before an actual capacity shortage situation occurs, may have an option value. As they put it; it might be valuable to pay an insurance premium today as a hedge against future outages (see also Stridbæk (2003), arguing in the same line).

Finally, demand response may reduce price volatility, thus contributing to reduce investors' uncertainty regarding investments in new capacity which may contribute to more timely investments. This will be described in the next section.

Overall, we can see that demand response may contribute to benefits and reduced costs of maintaining a reliable and well-functioning electricity system. Those savings may eventually be distributed among several participators in the electricity market and may benefit all customers; those on time-differentiated tariffs and those on traditional tariffs.

4.3 Reduced prices and price volatility

Highly volatile spot prices in the day-ahead market may occur due to the inelasticity of demand in the wholesale market, the non-storable property of electricity, uncertainty regarding demand that vary by time of year, week and day, available production and transmission capacity, bottlenecks and possible exercise of market power. Figure 4.3 show some examples of daily spot price patterns in the Oslo area.

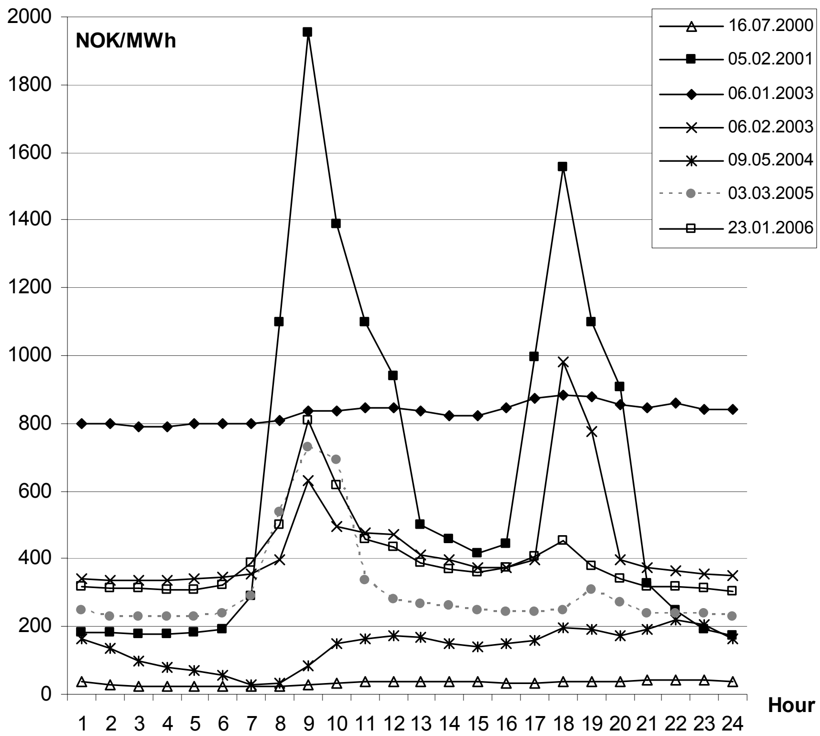

Figure 4.3. Different hourly spot prices for different days in the Oslo area.

As seen in the figure, prices may vary significantly during the day and between seasons. For instance, during 5 February 2001, prices increased substantially, indicating a power capacity shortage situation. We also see that prices were constantly high during 6 January 2003 due to the energy scarcity situation. Also shown is the peak price situation 6 February 2003, discussed in Section 3.1. Examples of low prices are 16 July 2000 and 9 May 2004. Although these examples indicate significant price variation, prices traditionally vary little within the day in Norway. This may however change if the capacity situation continues to tighten, and also as a result of new transmission capacity to countries with thermal power production.

Several analyses and simulations support that demand responsiveness provides lower prices during peak periods, as illustrated in Figure 4.1. For instance, Boisvert et al. (2002) analyses how price responsive load contributed to relieve the electricity system at a time when electricity peak demand reached all time high levels, using data from demand response programs in the state of New York. They found that the increase in demand response reduced prices and price volatility in both the day-ahead market and the real-time market. The authors claim that only a little price responsive load can go a long way toward reducing prices and price volatility. Caves et al. (2000) simulated the market impacts of demand and supply shocks in the Midwest in the USA under a scenario where only 10 percent of the load had a spot price based contract. The simulations show that prices would be reduced by as much as 73 percent from the highest prices. Jaske (2002) reported results from an experiment performed by CalPX, which operated a day-ahead market in the USA. By re-simulating market prices with hypothetical load reductions from price responsive load, they found the price to decrease by approximately 28, 58 and 75 percent for load reductions of 5, 10 and 15 percent in the peak price hour, respectively. Simulations performed by Nordel have shown that demand response in one region of the Nordic countries will contribute to stabilize the spot prices also in other regions (Kristensen et al., 2004). See also Braithwait and Faruqui (2001) or Hirst (2002b) for similar computations.

Furthermore, with respect to Figure 3.3 showing the market cross for the hour 17:00-18:00, 6 February; if for instance 600 MW less demand (approximately 3 percent of the total cleared demand) were bid into the Elspot market at some predefined level because of customers demand response, let’s say at prices above 500 NOK, this could have been enough to clear the market at nearly half the price this hour. Pettersen (2004) also shows how demand response may even out prices, not only between peak and off-peak periods of the day, but also between seasons.

As described in the previous section, investments in peaking units are highly risky because they need market clearing above their marginal cost, which occurs in constrained situations only. The length and height of the price peaks must be high enough to recover the investment costs. The more elastic demand is, the less volatile are the price, and the less is the uncertainties with respect to future income from investments in generators. Increasing demand response may therefore contribute to increased propensity to invest. Since the likelihood of extreme prices also is reduced, the chance for political interventions in the market by for instance imposing price caps may also be less. This further reduces investors’ uncertainty. Reduced volatility further reduces the retailers' price risk, which may lead to lower hedging costs at the financial markets. This provides benefits that in the next turn may be passed on to the consumers through lower tariff rates (Boisvert et al., 2002, Braithwait and Eakin, 2002, DOE, 2006). Lowering peak prices may ultimately also lower average prices, which may benefit also consumers who choose standard variable or fixed price contracts (Boisvert et al., 2002, Hirst, 2002b). However, as pointed out by Ruff (2002), bill reductions due to lower peak prices are rent transfers, not necessarily social benefits. Notwithstanding, many (for instance politicians) regard lower peak prices as benefits.

4.4 Mitigation of market power

In periods when peak demand approaches the limits of the production capacity, the market may clear at the steep part of the supply curve, as happened 6 February 2003 (see Figure 3.3). Then, producers with a significant market share may withhold enough power from the market to shift the supply curve to the left, and achieve higher price levels.[21] Taking 6 February 2003 as an example; if less than 3 percent of the total supply bid at the Nord Pool Spot was held back between 17:00-18:00, the price could have been doubled. However, the gains for producers of such attempts to exercise market power depend on the trade-off between selling less power to a higher price and selling more power to a lower price. The gain is higher if raising the price has little short-term impact on the demand. That is, with a significant share of consumption coming from consumers facing prices that do not vary by time of the day, the incentive for exercising market power is higher. On the other hand, with time-differentiated prices conveying real-time prices to demand responsive customers, companies holding back power from the market will have smaller impacts on the wholesale price. This reduces the profitability of exercising market power (see also Borenstein, 2000, Borenstein et al., 2000, DOE, 2006).

Another point is that when firms exercise market power, prices deviate from the cost of production. Reducing market power therefore contributes not only to reduced price volatility and price spikes, it reduces wealth transfer from customers to suppliers, and reduces efficiency losses in the market that occur from the difference of what the customers pay and the marginal production cost (Borenstein, 2002a, Lafferty et al, 2003). Besides, artificially high prices may lead firms, which are dependent on electricity, not to establish new businesses (Borenstein et al. 2000). De Vries (2003) and Twomey et al. (2005) further remark that since exercise of market power may distort prices, investment decisions with respect to new capacity may also be distorted. Mitigating market power by increasing demand response can thus also reduce uncertainties and improve the basis on which investors make their investment decisions.

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[21] Bye and Hope (2005) points out that any producer on the margin (in restricted price areas), even a small firm, may also exercise market power.

4.5 Other benefits

With automatic meter reading and direct load control technology, the opportunities for a retailer to differentiate its products from those of its competitors' is enhanced. Customers get more opportunities to choose from and can select the tariffs or products that are best designed for their specific wants and needs, and then tolerance for risk.

More accurate meter reading and billing of the customers, also prevent possible tactic meter reading by customers, and reduce the costs for customers as they no longer need to read and report their consumption manually.

Environmental benefits may also arise if increased demand response leads to a reduction in peak period emission that weighs up against possible increases in off-peak production emissions (Holland and Mansur, 2004, 2006). Holland and Mansur find that the impact on the emissions of SO_2, NO_X and CO_2 depends on the generation technology characteristics of the region they analyses. Another benefit is that new power plants or transmission lines with environmental impacts may not be needed if peak load is reduced.

In addition, some claim that energy efficiency may follow from demand response programs. For instance, Faruqui (1983) surveyed 12 TOU experiments and found that overall reduction in daily consumption generally occurs. In Puget Sound Energy Time-of-Use pilot program (PSE, 2003) it was documented a 1 percent average decline in total monthly energy use by TOU pricing participants. An IEA (2003) publication suggests that typical residential programs deliver approximately 2 percent reductions in energy consumed.

Since increased demand response provides a less varying demand, it will give more continuous utilization of generators, hence reducing starting and stopping of peak production, which tend to increase wear and tear for the generators (TU, 2005). Reduced demand during peak periods also reduces losses in the grid (Haugen et al., 2004).

Finally, under the existing load profile billing system, customers with little electricity consumption during peak periods and much electricity in the off-peak periods actually subsidize those with "the opposite" consumption pattern (Borenstein, 2002b, Borenstein, 2005). Instead of mainly paying the off-peak prices, as the customers would do with a time-differentiated price, a part of the customers' off-peak consumption is also charged the peak price, according to the adjusted load profile. Hunt (2002) remarks, “It is hard to think of any other industry where products whose price varies so widely are bundled together for sale”. Many customers consider this unfair, and may therefore want to be charged by time-differentiated tariffs.

5 Evidences of households' demand responsiveness

The release of many of the benefits depends on the consumers' demand responsiveness. It has therefore been important to quantify price elasticities by conducting time-differentiated pricing experiments. This section reviews some of the literature analysing data from these experiments.

In some European countries, time-differentiated electricity rates have been tested or been in use for some decades, while the U.S.' interest for demand response programs grew in the 1970's, partly due to the oil crisis and a growing environmental concern (Eto, 1996). [22]

Papers analysing consumers' responses to time-differentiated prices were few before researchers analysed a series of 16 experiments carried out in the US in the late 1970's and 80's. Two annuals of *Journal of Econometrics* were in its entirety devoted to many of these analyses (Aigner, 1984, Lawrence and Aigner, 1979). Since then, an extensive literature has developed on residential consumer response to variable pricing. Also, literature on load control of e.g. water heaters has been published, although not to the same extent. This review will therefore mainly focus on the time-differentiated pricing literature, but will also describe some experiments including load control. Furthermore, this review focuses on residential electricity consumers only.[23]

The first experiments usually featured the TOU rate. However, due to the static properties of this rate as described in Section 3.2 (it is constant in each time block regardless of varying conditions in the electricity system), more dynamic rates, such as real-time market prices or the CPP rate, have been tested recently. Most of the papers on customers' responses to time-differentiated pricing have therefore analyzed TOU programs. Very few papers where end-users at the household level have been offered spot price tariffs, are published.

Usually, the results from analyses of consumers' responses are reported in terms of elasticities. The most common is the own price elasticity (usually only referred to as the price elasticity) and the elasticity of substitution. The own price elasticity is defined as the percentage change in quantity demanded, divided by the percentage change in price. The elasticity of substitution is the negative of the percentage change in the ratio of peak to off-peak consumption, divided by the percentage change in the ratio of the peak to the off-peak price.[24]

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[22] Time-of-use (TOU) rates have been reported in use as early as 1913 (Mountain and Lawson, 1995), and water heater load control as early as 1934 (Hastings, 1980). Since 1965, French households have been offered the choice between a standard flat rate and a rate with two daily pricing periods (Aubin et al., 1995), in the UK a large TOU tariff experiment was conducted in 1966/67 (Hawdon, 1992) and Finland has offered consumers a TOU rate since 1970 (Kärkkäinen, 2005).

[23] For papers analyzing or reviewing commercial and industrial customers, see for instance Aigner and Hirschberg (1985), Aigner et al. (1994), Faruqui and George (2005), Ham, Mountain and Chan (1997), Hopper et al. (2006), Mak and Chapman (1993), Schwarz et al. (2002).

[24] According to King and Chatterjee (2003), an elasticity of substitution of 0.17 is consistent with a peak-period own price elasticity of approximately -0.3.

5.1 TOU experiments

The results from the analyses of the 16 U.S. projects conducted in the 1970/80's differed, and questions were raised how to transfer the results to other regions, which was one of the intentions with the experiments (Aigner, 1984, Lawrence and Aigner, 1979). Initiatives were therefore taken to investigate whether consistency could be found across the experiments if the differences between the experimental characteristics where controlled for. Caves et al. (1984) reviewed several of the experiments and selected five with sufficiently high quality that could be used to pool the data. Their analyses found consistent price responses across the experiments when the effects from weather, appliance holdings and household characteristics were controlled for. They found the substitution elasticity to vary depending on the stock of electric appliances in the homes. For a typical customer the elasticity was 0.14, for a household with no major appliances it was 0.07, while a household with all major electric appliances had a substitution elasticity of 0.21. Baladi et al. (1998) report similar findings from a later U.S. experiment.

A Norwegian TOU electricity pricing experiment took place during the period from 1984 to 1987 and included 374 households that volunteered for the experiment. Vaage (1995) found the results to be quite comparable with the results from the U.S. experiments. The elasticity of substitution varied between 0.13 in the winter and 0.24 in the spring, with an average over the whole period of 0.18. Hence, price responses were highest in the part of the year that is considered as off-peak period. Furthermore, nighttime consumption was more elastic than daytime consumption. Vaage also tested whether the elasticity changed during the two years the consumers faced the TOU rate. Although the substitution elasticity showed a slight increase from the first to the second year, he evaluated it to be too small to be given any weigh. Hauge (1993) analyzed data from the same experiment, and found somewhat higher responses, and also that responses were higher in households with a higher total consumption of electricity, living in detached houses and with alternative heating sources.

In Great Britain, a TOU pricing experiment took place from April 1989 to March 1990. Henley and Peirson (1998) analyzed data from this project, and found that consumers reduced daytime consumption in response to the prices and that the price response was dependent on temperature (price elasticity was highest at 10°C). They reported price elasticities of -0.10 and -0.25 at 10°C. In an earlier work, Henley and Peirson (1994) found that responses were different depending on the customers' consumption strata, with higher responses in the highest strata.

Train and Mehrez (1994) analysed a TOU tariff experiment in California in 1985 and 1986. They estimated price elasticities of –0.15 in the peak and –0.25 in the off-peak period, and also found that peak and off-peak consumption are substitutes because of positive cross-price elasticities.

Filippini (1995a) analyzed panel data from 21 cities in Switzerland, from the period 1987 to 1990, where consumers faced a time-of-use tariff or a two-part tariff. Unlike most other studies, which use micro data, this study was based on aggregated cross-sections data at city or state level. Filippini found elasticities that are much higher than in most other studies. He found peak elasticities to range from -1.29 to -1.50 and off-peak elasticities from -2.36 to -2.42. Another analysis by Filippini (1995b), this time using micro data, confirmed the previous results with estimated elasticities in the same range.

In a Japanese TOU experiment in Japan, Matsukawa (2001) found price elasticities close to those in Filippini (1995). However, contrary to the Swiss results, Matsukawa found peak elasticities (-0.70 to -0.77) to exceed off-peak elasticities (-0.51 to -0.72).

A quite new residential TOU program carried out by Puget Sound Energy in the USA in 2001/2002 showed a shifting of 5 – 6 percent of the customers' consumption out of high-priced periods (Williamson, 2002). This result must be seen in light of very low price differentials in the experiment, which gave limited incentives for the consumers to shift their energy use.

These results indicate that customers do respond to time-differentiated prices, but the extent to which they respond varies between the experiments. According to Braithwait and Eakin (2002), the average elasticity of substitution from traditional TOU programs is about 0.15. According to King and Chatterjee (2003), the average own price elasticity from all types of programs (including CPP and automated thermostat control programs, discussed in the next section) is -0.3.

5.2 Dynamic pricing and direct load control experiments

Dynamic rates have often been combined with signal lamps or enabling technologies. For instance, Räsänen et al. (1995) analysed data from a voluntary dynamic pricing experiment in Finland during 1988-1993. A yellow signal lamp warned the customers one day in advance that the critical peak price could be charged their usage, and a red lamp signaled the customers during the peak hours that the critical peak price was actually in effect. Räsänen et al. found it important to analyze impacts of the rates at an individual customer level, since the customers' responses differ. In their data they found an active and a passive response group. The passive group reduced their consumption in peak period with 16 to 26 percent while the active group showed strong responses with 60 to 71 percent reductions.

Elecricité de France has for a long time offered their electricity consumers time-of-use tariffs. From 1996 the French electric utility also introduced critical-peak price tariffs for its residential consumers. Prior to this introduction, from 1989 to 1992, they conducted an experiment with this so-called tempo-tariff. With this tariff, the year is divided into 22 red, 43 white and 300 blue days, and each day has a peak and an off-peak period. The red days charged electricity consumption the highest prices and the largest peak/off-peak price ratios, and the white days the lowest prices and smallest ratios. As in the Finnish experiment, the end-users were notified with a signal lamp of the next day's price structure at the end of each day. The prices accompanied with each of the days were fixed and known for the customers, but the colour of the days was unknown until the evening before. Aubin et al. (1995) found high elasticities in this experiment, with a peak price elasticity of -0.79 and off-peak elasticity of -0.28.

A large-scale project in the USA tested a real-time market price on households, with a notification by e-mail or phone if the next day's price exceeded USD 0.10. The analysis of the data found price elasticity of -0.04. This somewhat low result must be seen in light of prices that were not particularly high in the test period (Summit Blue Consulting, 2004).

The above experiments did not assist the consumers' load reductions by automatically controlling loads. Other experiments have done this by offering enabling technologies such as direct load control, combined with time-differentiated pricing in order to enhance the consumers' price response. King (2004) made a survey of programs with dynamic pricing of electricity and/or with automated control. The intention of the survey was to compare the peak demand reducing performance of programs with only dynamic pricing or with only automated control, with programs that combined those two demand response measures. He found load reductions for programs that integrated dynamic pricing with automated load control to be on average 53 percent larger than load reductions in programs with only load control. He further found the integrated programs to give 102 percent larger reductions compared with programs with only dynamic pricing.

An example of one such project is a program in the USA that used a critical-peak price tariff together with an interactive communication system. This system allowed the utility to send a signal to the consumers when critical prices were expected and also allowed the customers to program and schedule some of their appliances in order to modify the consumption according to the prices. Braithwait (2000) analyzed data from the project and found elasticities of substitution of approximately 0.3.

Hartway et al. (1999) found load reductions of up to 1.95 kW (approximately 35 percent reduction) in another program in the USA. They attributed these high responses to the high price differential (6.5:1), and to customers' programming of their air conditioners using an advanced energy management system.

The results from the recently finished Statewide Pricing Pilot in California (Faruqui and George, 2005, CRA, 2005) further illustrate the same results. Although comparisons between the different customer groups in the program should be made with care, the results showed that customers with enabling technologies responded more than customers without this equipment.

6 Conclusion

Increasing short-term demand response in the Norwegian electricity market may increase efficiency, improve system reliability, decrease price volatility and mitigate exercise of market power. These market performance improvements may contribute to lessen uncertainties for investors of new capacity due to a market framework that may become more predictable, thus providing more timely and correct investments decisions. These benefits may prove valuable as the Norwegian and the Nordic market now enter a period with tighter conditions and with uncertainties regarding new investments in electricity production.

Approximately 40 percent of the *annual* electricity consumption, and probably more than 40 percent of the power consumption during cold peak periods, is metered by technologies that can only measure accumulated consumption. This prohibits the use of time-differentiated electricity tariffs that reflect wholesale prices because such tariffs require automatic meter reading. Consequently, households only face prices that are fixed for long periods of time, and have no incentives to adjust consumption according to the short-term varying market conditions signalled in the wholesale prices. This consumer group will therefore to a limited extent contribute to achieve the benefits described in this paper. Experiences from around the world have shown that households are responsive to the price. This suggests that households better integrated into the electricity market can be important contributors to increase demand response, and thus to improve the functioning and increase the efficiency of the Norwegian and the Nordic market.

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