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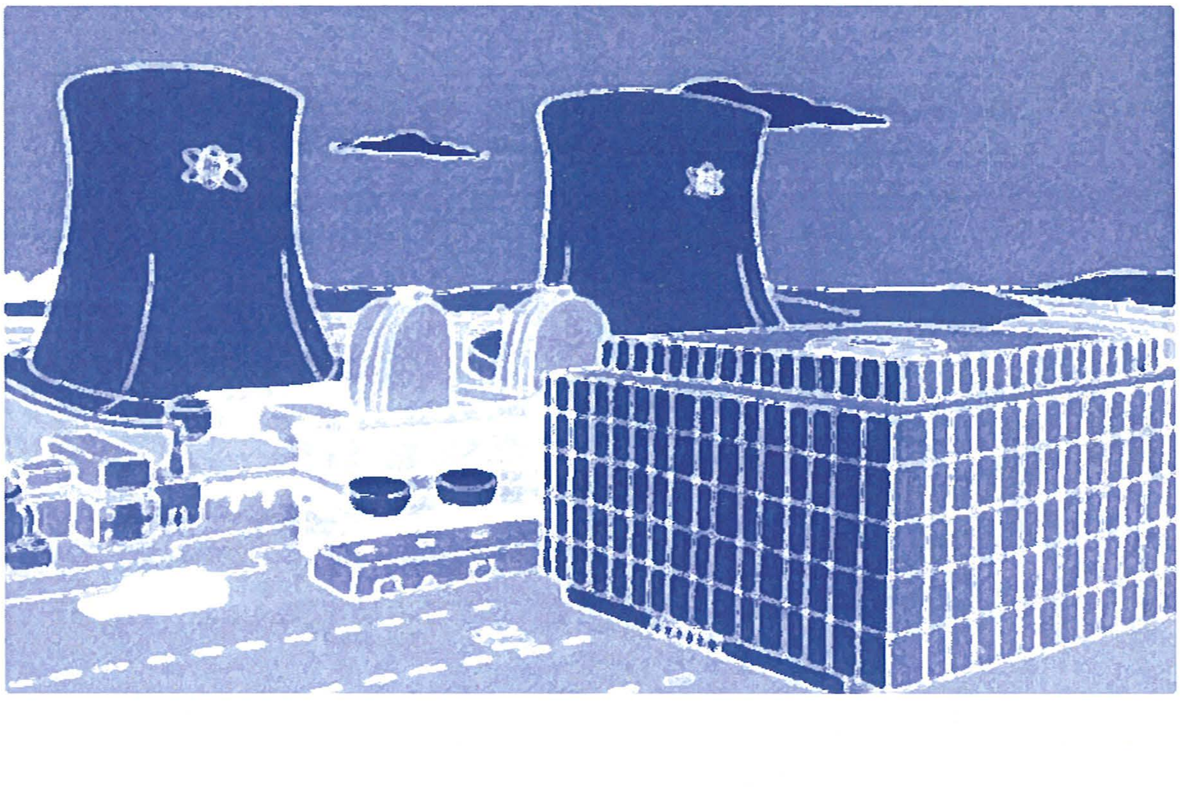
Pekka Sulamaa

ESSAYS IN DEREGULATED FINNISH AND NORDIC ELECTRICITY MARKETS



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Abstract

This monograph analyses the effects of Nordic electricity market deregulation on the efficiency of electricity pricing in the Nordic wholesale spot-markets and measures the possible productivity changes in the Finnish electricity market. The main object is to quantify the efficiency changes originating from the recent market reforms. Two different approaches are taken, one involving analysis of different market equilibria in the electricity spot markets by using numerically solved oligopoly models, the other involving measurement of the performance of Finnish electricity generating and distribution companies by using a non-parametric data envelopment analysis (DEA) method.

The introductory chapter presents the main types of reform that have been applied in electricity market deregulation. This is followed by a review of previous studies on the analysis of deregulated electricity markets, focusing on market competition models and on the efficiency measurement literature. Next, the structure of the three integrated electricity markets, Norwegian, Finnish and Swedish, are presented.

Chapter 2 analyses competition in the Finnish wholesale electricity market. A numerically solved static oligopoly model is developed and is calibrated to Finnish electricity generation and capacity data. The results indicate that, in the Cournot-Nash equilibrium, the degree of competition in the market may not be sufficient to guarantee more efficient pricing of electricity (using the 1994 base year price level as the criterion), as a result of the deregulation. The Cournot-Nash equilibrium price rose to FIM 219.604 per MWh from the initial level of FIM 160 per MWh in the base-year. The Cournot-Nash equilibrium simulation includes the nine largest Finnish generating companies as the potential price setters in the market. A perfectly competitive market equilibrium results in an equilibrium price of FIM 98.2 per MWh.

Chapter 3 extends the single-price single-region model to a three-country two-price region setting. The three countries are Norway, Finland and Sweden, which make up the two price regions: a combined Norwegian-Swedish market (Nordpool) and the Finnish market. The two markets are interconnected by a given transmission capacity, which is assumed to amount to 15 TWh per year. Several 'policy simulations' are solved. A normal hydro-year simulation is implemented by assuming an availability of an average annual hydro-power capacity of about 70 % of the theoretical maximum in Norway and Sweden. Compared to the reference year, the Cournot-Nash 'normal hydro year' equilibrium price fell in Finland from the FIM 160 per MWh to FIM 110.9 per MWh, while the Nordpool price fell its initial level of FIM 130 to FIM 79.9 per MWh. The opening of the Nordic electricity market has clearly improved the efficiency of electricity pricing.

Chapter 4 presents an analysis of different measures of technical efficiency and productivity for the Finnish thermal electricity generation. The sample consists of a plant-specific panel data from the period 1994-1996, with two potential outputs (electricity and heat) and three inputs (labour, fuels and capital) to describe the generation process. Productivity analysis, using the Malmquist index, shows that in the1994-1995 period, there was a growth of 4.5 % in total factor productivity. In the 1995-96 period, the growth was even higher at 7.1 %. The improvement in productivity turns

out to be due to improved technical efficiency. A bootstrap technique is used to construct the 95 % confidence intervals for averages of the Malmquist index components. The overall Malmquist index average does not display significant productivity improvement during 1994-95, whereas during the 1995-96 period the overall productivity change is significant at the 95 % level.

Chapter 5 analyses technical efficiency and productivity growth in the Finnish electricity distribution sector during the period 1996-1998. Total factor productivity is measured with Malmquist index. DEA-model that turns out to be robust with respect to its specification and identified well efficiency includes three output variables (energy delivered, number of customers and total road mileage within the distribution area) and three input variables (labour, length of transmission lines, transformer capacity). Technical efficiency scores indicate that an average technical efficiency is 0.75-0.8 depending on assumptions made. Scale efficiency turns out to be very high, with averages over 0.90. Productivity changes are moderate; with a 1.8 % fall during 1996-1997 and a 0.4 % rise during 1997-1998. Simulated confidence intervals shows that these values are not significantly different from one, i.e. that no significant productivity change occurs. The total factor productivity falls in 1996-1997 by 1.8 %, and rises by 0.4 % in 1997-1998. However, in both sub-periods, efficiency improves slightly.

Tiivistelmä

Tutkimuksessa analysoidaan kilpailulle avautuneita Suomen ja Pohjoismaiden sähkömarkkinoita. Tutkimuksen tavoitteena on kvantifioida kilpailun mahdollisia tehokkuusvaikutuksia sähkön hinnoitteluun ja tuotantoon. Tutkimuksessa analysoidaan sähkön hinnoittelun tehokkuutta numeerisesti ratkaistavien oligopolimallien avulla ja toisaalta mitataan sähkön tuotannon ja jakelun teknistä tehokkuutta ja tuottavuutta ei-parametrisella Data Envelopment Analysis (DEA) - menetelmällä.

Tutkimuksen johdanto-osassa luodaan katsaus kilpailumalleihin, joita on sovellettu sähkömarkkinoiden liberalisoinnissa ja esitetään alaa koskeva kirjallisuuskatsaus. Kirjallisuuskatsauksessa tarkastellaan sähkömarkkinoiden kilpailua koskevia tutkimuksia, joissa on käytetty lähinnä mikrotaloustieteellisiä osittaistasapainomalleja kuvamaan markkinatasapainoa. Lisäksi esitellään tutkimuksia, joissa sähkön tuotannon teknistä tehokkuutta ja tuottavuutta on mitattu DEA-menetelmällä. Johdannon lopussa esitetään Norjan, Ruotsin ja Suomen sähkömarkkinoiden rakenne.

Luvussa kaksi analysoidaan kilpailutasapainoa Suomen sähkömarkkinoilla, jossa yhdeksän suurimman suomalaisen sähköyhtiön oletetaan omaavan potentiaalista markkinavoimaa. Sähköyhtiöiden strategiseksi päätösmuuttujaksi oletetaan niiden tuotantotaso. Analyysia varten kehitettiin oligopolimalli, joka ratkaistiin numeerisesti (GAMS ohjelmalla ns. Mixed Complementarity Problem -ongelmana). Mallin parametrit valittiin siten että ratkaisu tuotti vuoden 1994 toteutuneen tuotannon tason. Cournot-Nash tasapainohinnaksi, joka kuvaa vuoden keskiarvohintaa tukkusähkömarkkinoilla, muodostui 219.6 markkaa per MWh, kun perusvuoden (1994) hinta oli 160 per MWh. Tämä hinnan nousu johtui suurimpien sähköyhtiöiden tarjonnan (hiilivoiman) supistamisesta. Täydellisen kilpailun tasapainossa hintatasoksi muodostui FIM 98.2 per MWh. Suomen sähkömarkkinat yksinään eivät näytä takaavan tehokasta sähkön hinnoittelua.

Kolmannessa luvussa analysoidaan sähkömarkkinoiden laajenemisen vaikutuksia sähkön hinnoittelun tehokkuuteen. Analyysia varten kehitetään oligopolimalli, jossa suurimmat sähköyhtiöt Suomesta sekä yhdistetystä Norjan ja Ruotsin sähkömarkkinoilta (Nordpool) kilpailevat keskenään kahden hinta-alueen markkina-alueella (Suomi ja Norpool). Kahta hinta-aluetta yhdistää sähkön siirtokapasiteetti, jonka oletetaan mahdollistavan noin 15 TWh:n vuotuisen sähkön siirron alueiden välillä. Normaalin vesivuoden skenaariossa oletetaan Ruotsin ja Norjan vesivoimakapasiteetiksi noin 70 prosenttia teoreettisesta maksimikapasiteetista. Tällöin Cournot-Nash tasapainohinta Suomessa on FIM 110.9 per MWh ja Nordpoolissa FIM 79.9 per MWh. Kilpailun ulottaminen pohjoismaihin näkyy siis selvästi alempana hintatasona Suomessa.

Luvuissa 4 ja 5 analysoidaan sähkön tuotannon ja jakelun tuottavuutta Suomessa DEA-menetelmällä. Luvussa 4 tutkitaan lämpövoimalla Suomessa tuotetun sähkön teknisen tehokkuuden sekä tuottavuuden kehitystä 1994-1996. Malmquist-indeksien avulla laskettu keskimääräinen kokonaistuottavuuden kasvu on 4.5 % 1994-1995 ja 7.1 % 1995-1996. Tuottavuuden keskimääräinen kasvu1995-1996 on tilastollisesti merkitsevää 95 prosentin Bootstrap-menetelmällä simuloidun luottamusvälin mukaan.

Suomen jakeluverkkotoiminnan tehokkuuden ja tuottavuuden arviointia (Luku 5) varten on käytettävissä jakeluyhtiökohtainen tuotos- ja panosaineisto vuosilta 1996 - 1998. Valitussa DEA-mallissa on kolme tuotosmuuttujaa (siirretty energia, asiakkaiden lukumäärä ja jakelualueen tiekilometrien määrä) ja kolme panosmuuttujaa (työ, jakelulinjojen pituus ja muuntamokapasiteetit). DEA-mallin antamat tulokset osoittavat, että yhtiöillä on keskimäärin n. 15-20 % (oletuksista riippuen) panosten vähentämistarve teknisen tehokkuuden saavuttamiseksi. Tehottomuus ei kuitenkaan riipu skaalaetujen käyttämättä jättämisestä. Jakeluyhtiöt toimivat skaalatehokkaalla (lähellä vakioskaalatuottojen mukaista) tuotannon tasolla. Tuottavuustulokset osoittivat, että kokonaistuottavuuden kehitys vuosina 1996-1997 ja 1997-1998 on suhteellisen maltillista.

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Dr. Miika Linna, a long-time friend, wrote a beautiful piece of pascal code with which the bootstrap analysis was performed.

[1] I am now aware that during the 2nd World War the FAF did not in fact have Bf 109 G-10s (Messerschmitt); only G-2s, G-6s and G-8s

I also thank director Asta Sihvonen-Punkka, head of tariff unit, Antti Paananen and senior adviser Kari Lavaste of the Energy Market Authority for their contribution to the chapter on efficiency of the Finnish electricity distribution and for allowing me to use the electricity distribution database for this study. Professors Leena Korpinen of the Tampere University of Technology and Raimo P. Hämäläinen of the Helsinki University of Technology have also helped and advised me with electricity markets modelling issues.

Richard Burton moulded skilfully this text into more accurate and accessible English.

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Contents

1 Electricity sector on the move

The electricity supply industry has traditionally been organised as a vertically integrated monopoly subject to public regulation. Regulation of the industry is primarily motivated by the existence of natural monopoly conditions, externalities and public good characteristics. These stem from a number of characteristics prevailing in electricity industry: electricity is a non-storable good, capacity constraints on generation plant cannot be broken for long periods of time without risk of costly damage, demand is highly price inelastic, the supply is capital intensive while the physical properties of transmission and distribution make it critical that supply and demand exactly match continuously. In a natural monopoly industry a single firm produces a range of products at lower cost than many firms would do. Economies of scale and scope[1] in production mean that unit costs decline throughout the relevant range of production as output increases. While on the whole, electricity supply may be characterised by conditions of natural monopoly, externalities, and public goods, some of its functions do not have these features. The main functions within the electricity supply industry (ESI) are generation, transmission (high voltage networks), system control, distribution (medium and low voltage networks) and sales of electricity (wholesale and retail sales).

Transmission, distribution and system control functions conform well to the natural monopoly characterisation. Building networks and establishing country-wide connections require large scale investments.

[1] A more general criterion of a natural monopoly is based on the notion of sub-additivity of costs, see Baumol [13].

Networks involve setting up more or less permanent connections with customer premises. A centralised system-control operation, moreover, provides the necessary co-ordination and trading functions that are specific to electricity sector. Centralised control[2] of the grid system is required to maintain system reliability[3] and to optimise the dispatch of physical generation.

Technological advances have improved the potential for competition in generation by reducing the minimum efficient plant size. During 1960s and 1970s new plants burning fossil fuels had to have a generating capacity of 1,000 megawatts or more to be efficient and the optimal capacity of a nuclear plant might have been even larger[4]. The advances in generation technologies have reduced efficient plant sizes since the early 1980s, which has facilitated a credible and feasible entry threat to the generation market. One example of the development is the Combined Cycle Gas Turbine (CCGT) technique[5], which allows plants to burn fuels at much higher temperatures, increasing their energy efficiency. Moreover, it was found possible to combine a simple gas turbine with a heat recovery steam generator and a steam turbine to produce the CCGT effect. Thermal efficiency increased by up to 60 percent, while minimum efficient plant size dropped from

[2] The centralised system control itself consists of dispatch, balancing, and electricity pool functions.

[3] If demand exceeds supply the costs of the consequent brownouts or blackouts are considerable, hence total demand and supply need to be in balance on a second-to-second basis

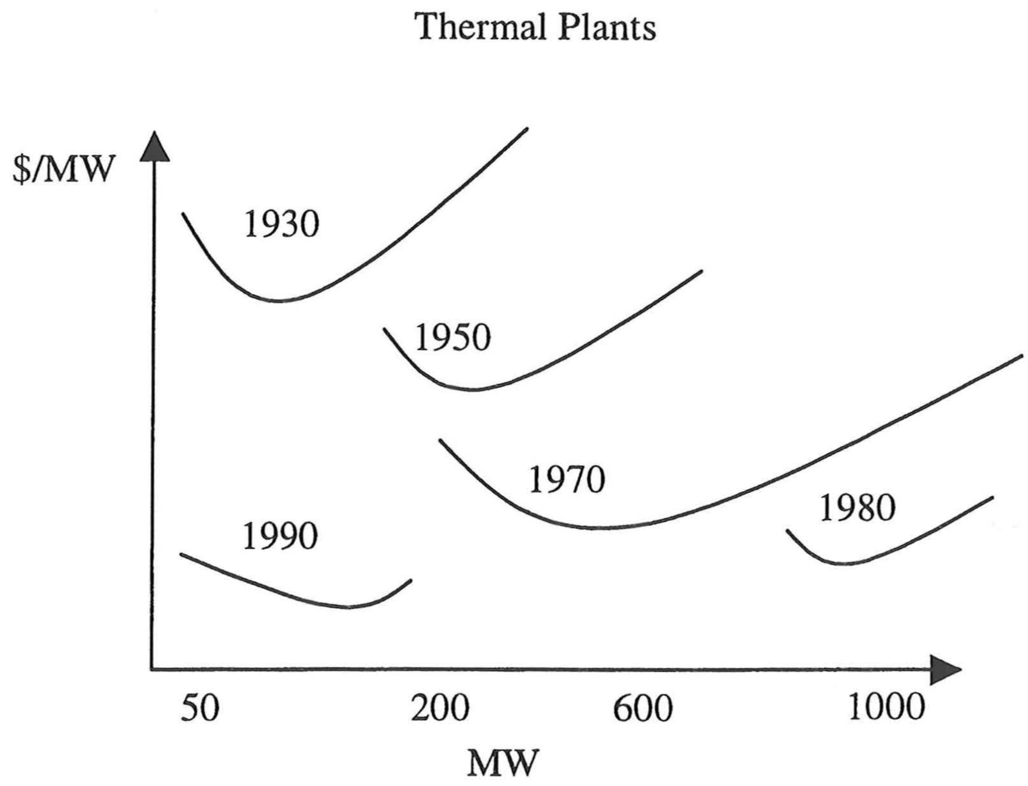
[4] This applied to large markets like the USA, whereas in Nordic markets the optimal sizes have been smaller.

[5] This was a spillover from military aircraft engine development.

around 1000 MW in the early 1980s to 50-350 MW in the 1990s[6].

The decline in optimal plant size after the 1980s is illustrated in Figure 1.1, reproduced from Casten [24]. The most dramatic increase in scale economies took place during 1945-1960, strengthening the view that the ESI is a natural monopoly industry.

Figure 1.1. Optimal generation plant sizes over time



An early example of entry to the generation market comes from the US, where the introduction of the Public Utilities Regulatory Policy Act in 1978 established possibility of entry of qualifying facilities to the generation market. These were small-scale generating facilities from which the power companies were obliged to purchase surplus electricity at rates set by the state regulatory authorities. The regulated prices were based on estimates of the costs of the power companies.

[6] Another important technological development, that facilitated the competitive market regime, was a reduction in transmission losses, which enabled generators for hundreds of kilometers apart to compete with each other.

In some states these costs were over-estimated, which quickly induced entry of an excessive new independent capacity to the market.

Christensen and Greene[29] provided evidence that the US electricity generation plants were already operating in the flat area of the average cost curve in the 1970's. They argued that policies to promote competition in electric power generation could not be defaulted in terms of sacrificing economies of scale.

There are no obvious technological reasons why wholesale or retail sales of electricity should be characterised as natural monopolies. The reason why these functions have traditionally been regulated (and still remain regulated in most countries) is that introducing competition in sales of electricity also implies, de facto, competition in generation, but not vice versa.

1.1 Outline of the study

This monograph analyses the economic consequences of the electricity market deregulation that has taken place in the Nordic countries, and attempts to quantify possible efficiency changes by two different approaches. One of these involves a numerical solution to a set of models representing competition in the Nordic electricity (spot) markets. The other approach measures the performance of Finnish electricity utilities (both generation and distribution) before and after deregulation by a nonparametric data envelopment analysis (DEA) method. The numerical modelling approach evaluates the effectiveness of competition in pricing of electricity (the marginal cost pricing representing the efficient benchmark), while the DEA approach determines productive efficiency by measuring the distances of observed from derived efficient input usage levels in the Finnish electricity distribution and generation sectors (the derived production function being the benchmark in these sectors).

This chapter is organised as follows: the following sub-sections provide some further explanations for why competition may improve efficiency in the electricity sector, and the main objectives of electricity market deregulation are also stated. This is followed by a presentation of different models of deregulation that have been applied worldwide. The next two sub-sections discuss the main studies that have been applied to electricity market deregulation. The three sections (1.7 - 1.9) after that present the distinct features of the two electricity markets analysed within this study: Norway, Finland and Sweden. These countries have perhaps gone furthest (together with the UK) in introducing competition to sales and generation of electricity.

Chapters 2 and 3 cover the numerical model simulation approach for analysis of effectiveness of the competition. Chapters 4 and 5 present measurement of productive efficiency and productivity in the Finnish electricity generation and distribution.

Chapter 2 analyses competitive models and numerical solutions of market equilibria in the Finnish electricity market alone. The model developed for this study extends[7] the analysis by Andersson and Bergman [6] of the Swedish electricity market. The present re-

[7] For example, by using a calibration method which endogenises the mark-ups, and solving the model as a market equilibrium problem instead of a planner problem.

sults imply that the degree of competition may not be sufficient in the Finnish market alone when the 1994 base year price level (representing an equilibrium before the deregulation) is used as a criterion.

Chapter 3 extends the single price region model to a three-country two-price region setting. The three countries are Norway, Finland and Sweden, which make up two price regions: a combined Norwegian-Swedish market and the Finnish market. The division into two price areas is motivated by the fact that at the time of electricity market deregulation in Finland and Sweden, Norway and Sweden were running a joint market place, the Nordpool, while electricity flows from Finland to the Nordpool was subjected to a tariff. The two markets are interconnected by a given transmission capacity. Subsequently the three countries were 'integrated' by the abolition of border costs. Several 'policy simulations' were solved. A normal year simulation was implemented by assuming an average annual capacity (about 70% of theoretical maximum) of hydro generation in Norway and Sweden.

Other simulations included a dominant-firm vs. competitive fringe market and elastic demand simulation. In the competitive fringe Cournot equilibrium the Nordpool price level was higher than in the normal year simulation, while the Finnish price level remained the same. This reflects the fact that Nordpool is a less concentrated market and the residual demand over which the dominant firms compete was relatively smaller than in Finland. In the elastic demand case a price elasticity of -1.1 was assumed instead of the -0.6 assumed above. As one would expect, the Cournot equilibrium moved towards a competitive outcome as the demand elasticity was increased.

The main focus of chapters 4 and 5 is on measuring the performance (efficiency and productivity) in the Finnish electricity distribution and generation market before and after the market reform. Deregulation and privatisation in general are two policy issues where measurement of productive efficiency have been used to quantify changes that are predicted qualitatively by theory. The main contributions of these chapters are twofold: firstly they represent the first applications of productive and efficiency analysis to the deregulated Finnish electricity sector. Previous studies have involved mainly partial performance measures, such as labour productivity within the sector. Secondly, the application of sensitivity analysis to a nonparametric data envelopment analysis, especially using bootstrapped confidence intervals to the measured average productivity indices. The used database, especially in chapter 5, which analyses the performance of the Finnish electricity distribution sector, was exceptionally extensive even by international standards.

Chapter six draws the conclusions of this study.

1.2 Towards competitive markets

Liberalisation of electricity markets around the world is based on the principle that competition has become feasible (via changes in technology and political climates), especially in electricity generation. The fall in optimal plant sizes has been a major economic and technological factor in the movement towards deregulated electricity supply industries. Simultaneously, there was a change in the political climate toward more marked oriented policies in early 1980s. In addition to the discredited Keynesian macroeconomic policy in the 1970s, there was growing concern that excessive regulation was holding back many developed countries, especially Western Europe, against the competition from countries like Japan and East Asian NICs.

The main economic argument for deregulating a previously regulated market is that competition provides stronger and less manipulable incentives for efficient production and pricing than regulation. At least in the case of cost-of-service regulation, it may be argued that electricity utilities managers' incentives were not always geared towards cost minimisation, as most of the operational risks could be passed to their customers.

Joskow and Noll [67] point out that in accordance to the public interest theory of regulation, the effect of deregulation is positive in terms of efficiency improvements if the costs of regulation exceed the transaction costs of abolishing it plus the costs of any market failure. The so-called Chicago theory of regulation, due to Pelzman [92], Stigler [107], argue that regulatory agencies become the objects of 'captures' by various interest groups. This so-called theory of regulatory capture predicts that regulatory agencies will end up promoting producer groups' interests rather than the public interest. Deregulation will therefore increase welfare as broad, diffuse groups (usually customers) benefit relatively more than well-organised, compact groups (frequently firms). Possible efficiency improvement with a deregulation would in general originate; first, as inefficient operations in the insulated market regime would be curtailed and second, as rents that accrue to well-organised groups would be dissipated.

The 'wires' business of the ESI (transmission and distribution) will remain regulated for the foreseeable future. Unbundling these functions from the competitive ones has, however, raised interest in developing regulatory schemes that would yield efficiency improvements in the natural monopoly sectors as well.

The so-called 'new economics of regulation' puts emphasis on informational and incentive problems in the regulatory process. Norwegian electricity distribution sector is a good example of a regulated market where the incentives of the regulatees are explicitly taken into account in the regulation rules. Chapter 5 elaborates this further.

As was pointed out, the economic argument for introducing a competitive market regime, whenever it is feasible, is that competition creates stronger and less manipulable incentives for efficient production and pricing. These incentives are of course strongest in the extreme case of a perfectly competitive market. Traditional regulatory schemes, like the cost-of-service regulation, suffer from inadequate incentive structure to foster efficient operation of the regulated business. The UK and Norwegian experiences (the two pioneering countries in electricity market deregulation) indicate that the regulated monopoly companies suffered from inefficiently large investments, resulting in over-sized generation capacities. The resulting excess capacity costs were recovered by monopolistic pricing in long-term contracts, with extensive price differentiation across consumer groups, see Von der Fehr *et al* [117]. Under the regulatory regime most of the utilities' operational risks could be passed to their customers. Hence it was the customer who paid for managerial mistakes in investment, changes in demand, unanticipated technological obsolescence and any other cost shocks that may have occured.

The main underlying objective of the current wave of electricity market deregulation is to achieve higher economic efficiency in electricity markets. Economic efficiency means that:

- Production takes place with a cost minimising input combination, and investment ensures an efficient capacity level (marginal cost of extra investment equals the shadow value of the extra capacity)
- Consumers get the right signals to use electricity (social marginal cost equals private marginal cost)
- Prices reflect the marginal cost of resources at different times and locations to ensure that correct amounts are produced and production is allocated to consumers that value it most

Other key objectives are:

- Security and high quality of supply
- Environmental performance
- Social objectives

Security and quality of supply refer to both system reliability (short run) and adequate capacity (long run) investment.

The energy sector in general and the electricity sector in particular have a significant impact on the environment. In Finland electricity generation accounted for about 35 % of total CO2-emissions in 1990. Market liberalisation raises both challenges and opportunities in regards to emission controls. In countries where coal is used in power generation, competition may encourage the substitution of natural gas for coal-fired power generation, thereby reducing CO2 emissions. In England and Wales, electricity, coal and gas reforms led to a 25 % fall in the share of electricity in CO2 emissions over the 1990-1995 period. This was mainly due to the entry of CCGT plants and closure of older coal based plants. Market liberalisation induced a shift from coal to gas which led to reduction in emissions. The converse may occur in non-fossil fuel based systems like Norway's. Furthermore, when customers are free to choose their supplier they may choose to buy from suppliers that operate under lower environmental standards.

Social policy objectives are especially important with respect to consumer protection against degradation in quality of service. In Finland, during the drafting of the Electricity Market Act in 1994/95, the consumer ombudsman stressed the need to include an obligation for retailers to supply those of their customers who were outside the competitive market.

A fundamental issue in introducing competition to electricity markets is reconciling the freedom of large number of actors to trade individually with the optimal operation of the interconnected system. Different means by which competitors can access the regulated monopoly functions of an ESI have been applied and are reviewed in the next section.

1.3 Models of deregulating the electricity supply industry

The market reforms implemented in different countries vary in terms of market organisation, system operation, transmission pricing, congestion management etc. These differences often reflect characteristics of the existing systems. Some countries have favoured a partial liberalisation (e.g. most European countries and the US, with the exception of a few states) while others have opted for full-scale deregulation (the UK, Finland, Sweden and Norway, California). The former typically opened only generation to competition, while the more radical reforms extended competition to small scale customers. Currently, Finland has advanced perhaps furthest in introducing a competitive electricity market environment (see next chapter).

1.3.1 Franchise bidding

In franchise bidding authorities invite offers to take over and operate distribution utilities and to exclusively supply a franchise area for a limited time. In this model sales and distribution are bundled together and auctioned off. While franchising contracting enhances efficiency via the need to win the contract, there are a number of weaknesses in the scheme. The general monitoring problem is one; repeated bidding requires extensive control by the regulatory authority. Also, while competition may be strong during the bidding stage, there will be no direct competition during the licence period.

1.3.2 Competitive bidding

In the competitive bidding model, competition takes place for the right to build new generation capacity, and does not include the sales market. This is a model of competitive procurement for new generation capacity, and has been argued to be sufficient to achieve efficiency improvements in the electricity sector as generation represents a fairly high cost share (about half) of the total costs.

Various versions of the model exist depending on the bidding rules. In mandatory bidding utilities are obliged to conduct competitive bidding for any required new capacity. In the voluntary bidding model utilities can freely choose whether to bid for the contract.

The disadvantage in this model is the lack of any direct market discipline on generators via the competitive sales market. The product that is auctioned is not sold in competitive markets. The effectiveness of the bidding depends largely on the eligibility rules governing participation in the process. If external participants as well as all competitive utilities are allowed to participate, then the model is likely to improve efficiency in generation.

This model is often applied as the first step to deregulated electricity markets.

1.3.3 Wheeling

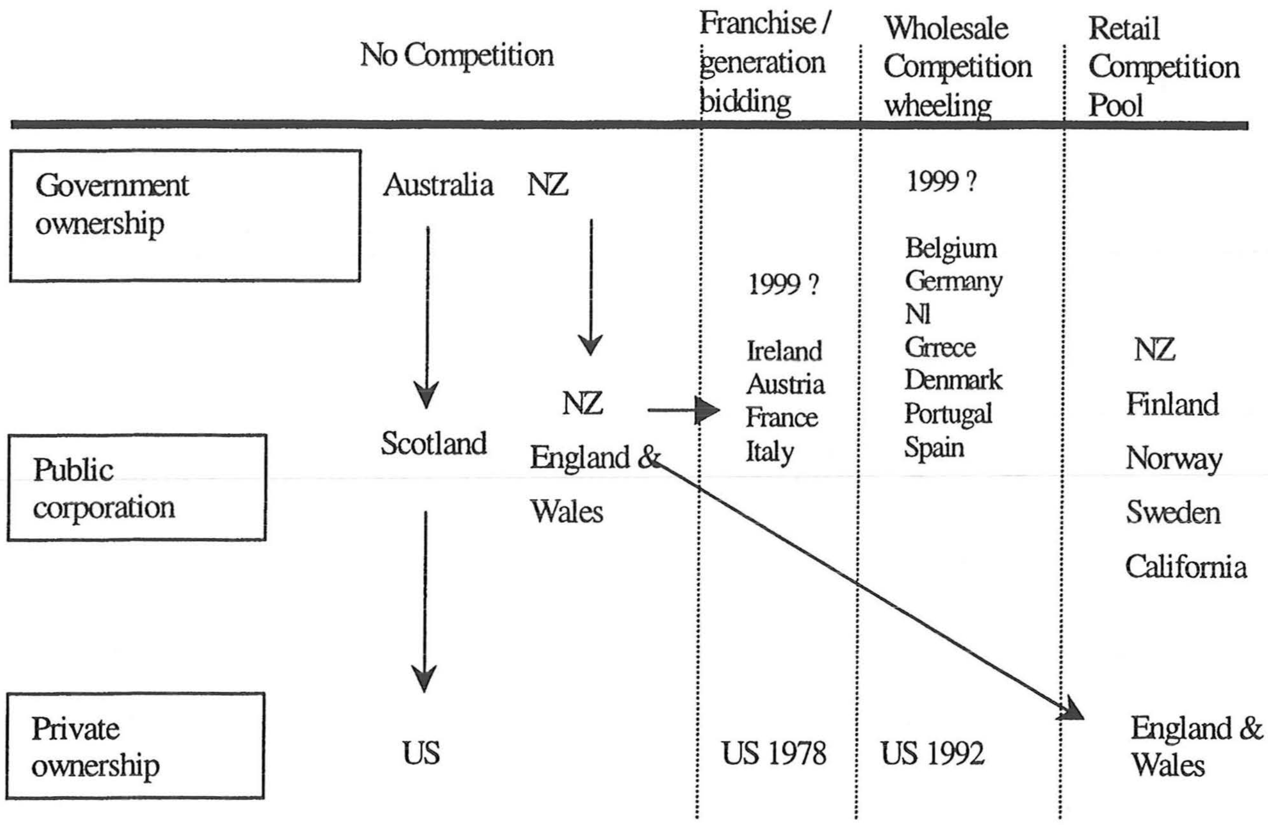
In both of the above models consumers are captive, i.e. they have no choice of electricity supplier. Competition in sales would also imply competition in generation, but not vice versa. In the wheeling reform model customers can choose between suppliers and the utility is obliged to transfer (wheel) third party electricity in its supply area. This model also implies competition in generation as the generators have to compete for customers. The distinguishing feature of the wheeling model is individual access for third parties to the network and balancing services. The wheeling model involves only partial disintegration of network services from competitive operations. Disintegration occurs only to the extent that competitors enter the supply market using the incumbent utility's network. The wheeling model is based on priority of grid utilisation by the incumbent grid operator. The model poses problems of distributing scarce transmission capacity, especially if the third party is introduced stepwise; those who are first eligible gain at expense of others who must wait for the capacity.

1.3.4 Competitive Pool

In contrast to the wheeling model the Pool model of electricity market deregulation introduces generalised access to the monopolistic services. A pool is a market place for generators, distributors and final consumers. The pool model produces a market price for electricity. Two versions of the pool model have been applied: a voluntary and mandatory pool. In a mandatory pool generation and transmission are centrally operated at the physical level. Plants are centrally dispatched based on the bid prices into the pool. In a voluntary pool model the balancing functions are centralised, but generators are not centrally dispatched. To fulfill the balancing function (i.e. maintaining the system balance) in a voluntary pool a limited number of flexible power plants is required for the use of the system operator. In the voluntary pool model real-time plant dispatch is still carried out by the central system operator but not merit-order dispatch. Merit-order dispatch is determined from decentralised trading at the pool.

Figure 1.2 summarises in two dimensions some of the electricity market reforms that have been applied. The boxes indicate different ownership structures: government controlled, public and private companies. Government control means that the state has direct ownership and managerial control over industry. This form of ownership emphasises electricity as an 'infrastructure' good. The public corporation mode of ownership refers to the case where government has control over the corporation, which in turn manages the industry. In this case the government is not directly involved in day-to-day business operations. The third structure is private ownership, currently popular in the UK and United States. The columns in the figure refer to the form of competition introduced in the electricity markets mentioned.

Figure 1.2. Models of electricity market deregulation



There is a large degree of heterogeneity in ESI organisation and structure between countries. The figure below illustrates differences in electricity sector structures between various OECD countries. As the degree of vertical and horizontal integration varies between countries so will their stance toward deregulating the industry.

1.4 Applied reform models

This section briefly considers some applications of the above-mentioned reform models. A more comprehensive discussion of these models and their applications can be found in Yajima [122].

1.4.1 Franchise bidding

Franchise bidding was applied in the US before the Carter administration introduced more comprehensive deregulation. Newbery [88] argues that the franchise contracting in the US was fairly efficient; the long contract periods (20-30 years) enabled re-payment of even large investments, and private investment took place.

1.4.2 Competitive Bidding

Competitive bidding has been introduced in several countries. In the US, for example, the Public Utilities Regulatory Policy Act (PURPA) included competitive bidding as the main element of the reform.

The Energy Council of the EU provided a comprehensive set of guidelines in June 1996 as to the nature and size of electricity deregulation in European countries. The requirement to open up the electricity supply markets was set out in EU Directive 96/92. This provides for the progressive introduction of a free market. Commencing in 1999, the directive stipulated that 26% of the market should be open, corresponding to customers with an annual requirement of 40 GWh or more. This competitive threshold was to be progressively reduced to 20 GWh per year in 2000 (equivalent to 30% of the market) and to 9 GWh per year in 2003. Further opening of the supply market was to take place only in 2006, subject then to EU Council of Ministers approval The European Commission has two different propositions for methods of deregulation: third party access and a single buyer model. The single buyer model resembles the competitive bidding model, i.e. it is a system of competition at generation level alone. This proposition has been suggested by France mainly to safeguard Electricite de France. France and other advocates of the single buyer model (Ireland, Austria, and Italy) claim that it gives the single buyer incentive to force other producers to compete for the delivery in order to secure best price, which would then be passed on to all customers.

1.4.3 Competitive Pool

The competitive Pool model has been applied in both the mandatory and voluntary form. The mandatory pool model was applied in the UK electricity industry reform, so that trading now takes place in the form of pure supply bidding. The central market place, the Pool, is run by the grid company, the National Grid Company Plc. Recent discussions have focused on whether demand side bidding should also be allowed, and hence a move towards the voluntary pool model. In September of 2000 the British Government published a reform proposal under the heading "Reform of Electricity Trading Arrangements". The government hopes the proposal will make the UK system less centralised. Both demand-side bidding and the possibility of signing bilateral contracts are included in the proposal.

Australia is another example of the mandatory pool model of electricity market deregulation.

The voluntary pool model has been adopted by Scandinavian countries, Argentina and California. Norway was the first Nordic country to deregulate its electricity market with the Energy Act in 1991, followed by Finland in June 1995 with the Electricity Market Act. In August 1996 the Finnish electricity exchange, EL-EX, started to operate on a continuous time trading principle (delivery up to two hours from trade). In Sweden the new electricity market act came into force on 1.1.1996. This date saw also the establishment of a common Norwegian-Swedish electricity exchange based on the Norwegian market, Marked AS, which was previously owned by the Norwegian grid company Statnett SF. Half of the shares of Marked AS were acquired by the Swedish grid company Svenska Kraftnät, and the name was changed to Nord Pool A.S.A. The Nord Pool provides its services to Finland and Denmark, being the first international electricity market place. The Nord Pool operates two separate markets: a spot market, which is a day ahead market for physical deliveries, and a future market, which is a financial market for contracts up to three years ahead. In the spot markets, there are 24 hours to be traded for the next day. Based on the received bids the market operator clears each of the 24 markets by determining the equilibrium prices at which supply equals demand. Market clearing leads to a set of contracts based on amount of power to be delivered at the price of that hour. All bids are submitted by fax or computer. Individual bids are treated as confidential information by the market operator, while the market price and volumes are public information.

1.5 Previous studies on electricity pool models and efficiency measurement

At least two strands of research on competition in the electricity industry can be distinguished: engineering-style 'bottom-up' models of competition, and economic (both partial and general equilibrium) models of competition with special reference to electric power markets. The former explore the questions of optimal dispatch of power plants and optimal pricing of electricity, both in regulated and unregulated environments. Emphasis is on the importance of the correct modeling of electric systems from an engineering point of view (see for example Schweppe et al. [101]). Electricity transmission involves a possible network externality effect due to so called loop flow effect. Power flows over the network are governed by Kirchhoff's law, and according to the law power will flow over all available parallel paths between two points of transmission. Hence, the sale of power from a producer to a customer located at a different network node will produce additional power flows on all lines of the network, thus impacting the transmission capacity available for other transactions on all those lines. As a result, the ability to transport power between two points depends not only on the capacity of the transmission line connecting those two points, but on the capacity of all lines as well as on the pattern of output and consumption throughout the network. These network externalities are one of the reasons why centralized dispatch of all supply sources is needed to maximize social welfare resulting from the production and consumption of electricity.

While the engineering strand of research typically assumes competitive behavior by market participants or a social welfare maximizing planner, the partial equilibrium economic models also question whether the behavior in electricity markets is in fact competitive. Several theoretical models have been developed to examine the pricing behavior of firms in highly concentrated electricity markets under various institutional assumptions.

Patric and Wolack [120] have shown that peculiarities even in the institutional design of electricity markets may affect the form of market power. Wolack [119] has further investigated the implications of market rules on behaviour of market clearing prices by using an international database to analyse price variation in different types of deregulated electricity markets. He found, for example, that in electricity spot markets with mandatory participation tend to have more volatile prices than systems with voluntary participation.

Modelling applications on the two electricity pools, the UK pool and the Nordic pool, reflect some of these institutional differences. The UK pool is a mandatory pool which does not allow physical bilateral trades between generators and their customers. The UK system operator, the National Grid Company (NGC), runs both the financial and the physical side of the electricity trade. The generators offer bids of prices they are willing to provide at various quantities throughout the following day. The generators have two strategic means to affect the 48 half-hourly market clearing price: the price at which they are willing to supply electricity, and half-hourly decisions of whether or not to make a fixed portion available to the NGC to be called for power production.

The Nordic pool, Nord Pool A.S.A, is a voluntary pool in which generators and consumers voluntarily make decisions to sell or buy. The market participants in the Nord Pool indicate the amount of power they will actually sell or buy each hour on the daily power market as a function of the market clearing price. The difference from the UK pool is that there is no uncertainty in the quantity of electricity that is traded on the spot market the next day.

The next sub-section provides a survey of studies that hinge on one of the two main themes of this monograph: price determination in an auction-type electricity spot market. The survey focuses on economic partial equilibrium modelling applications on competitive electricity markets. Review of studies on the other theme of this monograph, a measurement of performance of electricity utilities, is then followed.

1.5.1 Electricity pool models - horizontal market power

Given the complexity of electricity markets the range of applications and modelling approaches has varied considerably, both in detail and content. This review focuses mainly on electricity pool models, particularly horizontal market power models.

As was noted earlier, a limited capacity for transport of power over the transmission grid and the resulting congestion may also be a source of market power (vertical market power). Transmission constraints can isolate markets (cause load pockets), giving local market power even to a small producer. Generators may strategically bid so as to cause the transmission line to be congested, giving it the residual load. Borenstein et al. [19] argue that players may have an incentive to reduce output so as to induce congestion of transmission lines, and that relatively small investments in expansion of the transmission system may lead to substantially lower prices through increased competition. Nasser [87] also suggests that it may be necessary to expand transmission capacity beyond that suggested by engineering considerations in order to alleviate any existing local market power. Economic models with multi-nodal networks and the loop-flow effect include those of

Hogan [63], Smeers & Jing-Yang [103] and Oren[91]. Other studies on deregulated electricity markets, that differ from our approach, include empirical studies on existing market data (Wolfram [121]) and experimental simulations of the bidding process (Weiss [115]) .

1.5.1.1 Supply-function approach of modelling an electricity pool

Bolle[17] and Green & Newbery[52] use Klemperer and Meyer's[72] supply function equilibrium (SF) model to capture the main characteristics of the first-price sealed bid repeated auction that determines the equilibrium daily price schedule in the UK pool.

Green & Newbery[52] solved the SF-equilibrium model[8] numerically in a duopoly setting, representing the two large generators in the UK market at that time, PowerGen and National Power. A Bertrand equilibrium was also solved as a benchmark. With the symmetric duopoly case the SF-equilibrium solution (using linear demand) indicated high mark-ups in the bidding. The SF-equilibrium system price was £ 41.1 per MWh compared to the competitive (Bertrand) price level of £ 23 per MWh . A deadweight loss of m£ 312 resulted from the exercise of the market power by the two large generators. The industry output was 214 TWh in the duopoly case compared to 248 TWh in the competitive equilibrium.

When the market structure was changed into one where five equal-sized generators competed, the SF-equilibrium system price was £ 27 per MWh and the consumer deadweight loss fell to £ 17 m. The

[8] This is reviewed in the next chapter.

authors conclude that in the short term, when the behaviour of the two generators did not induce entry, they could exert a considerable degree of market power. In the medium term, new entry to the market would take place, and in fact has done so.

Newbery [88] argues that the high degree of horizontal market power indicated by the above duopoly SF-equilibrium solution may have been overestimated as no explicit consideration of the threat of entry was taken into account. When the contestability condition[9] is met efficient pricing may result despite a high degree of market concentration. A possible way to achieve a competitive market outcome is to ensure an adequate fraction of the electricity trade taking place by bilateral contracts. According to Green & Newbery [53] a co-existing contract market will expose the generators to entry threat[10]. If the contract price rises considerably above the pool price level a new entry will look profitable. Furthermore, a large proportion of contracts in a generator's total sales gives it little incentive to manipulate the pool price.

There are some weaknesses in this modelling approach, which in practical applications can cause problems. Klemeperer and Myer [72] showed that a unique SF-equilibrium exists if and only if the demand schedule can be arbitrarily high. As in any actual market, so is the case with electricity, i.e., the demand variation is often bounded. With bounded variability (over time) of the demand the SF-equilibrium can

[9] See Baumol et al. (1982) on the theory of contestable markets.

[10] Green and Newbery (1992) mention for example that new technology using high efficiency combined cycle gas turbines makes entry at modest scales (300-600MW) simple and quick.

occur at any point between the upper and lower stationaries of the solution trajectory. The upper stationary corresponds to the traditional Cournot case while the lower stationary corresponds to a marginal cost pricing case. The large range of feasible equilibria reduces the predictive value of the model.

1.5.1.2 Auction modelling approach

Auction theory concerns modelling of price determination in a setting where buyers submit bids under various rules and typically with asymmetric information. The literature distinguishes four major types of auctions: the ascending-bid auction (or English auction), the descending -bid auction (or Dutch auction), the first-price sealed-bid auction and the second-price sealed-bid auction (or Vickrey auction). The seminal work on auction theory is due to Vickrey [113]. Of the four types of auction the first-price sealed-bid auction has been applied to the UK electricity spot market by Von der Fehr *et al.*[118]. In this type of auction, each bidder independently submits a single bid, without seeing others', and the object is sold to the party who made the highest bid. For a general introduction on auction models see Klemperer [73].

Von der Fehr *et al.*[118] explicitly modelled the step-like supply function that prevails in electricity markets, rather than approximating it with a continuous supply schedule. The model the authors developed is based on a first-price sealed-bid multiple unit auction model which allows discrete bidding strategies. The authors argued that modelling generators' bidding behaviour with an auction model brings realism to the analysis[11].

Von der Fehr *et al.*[118] analysed a generator bidding game for the case of two strategic generators, who simultaneously submit bids specifying the prices at which they are willing to supply electricity from each of their generating units. Market supply is derived by aggregation of these supply bids and demand is obtained as a random variable, independent of the price. The auctioneer equates supply and demand and dispatched units are paid the market price, which equals the offer price of the marginal operating plant.

Solutions to the model under pure and mixed strategy equilibria and various demand condition assumptions indicated that the system price would be above the competitive price. In this respect the conclusions are similar to those obtained by Green & Newbery[52]. Both models of the UK pool also predict that increasing the number of independent generators would result in more competitive bidding.

The main difference between the supply-function and the auction models is that the former assumes a smooth supply function assumption while the latter uses a step-wise supply schedule. The step-wise supply function is no doubt more realistic in the electricity business, but is fairly demanding in terms of analysis and also does not easily generalise to cases where there is collusive behaviour.

1.5.1.3 Traditional oligopoly models

Traditional oligopoly models, à la Cournot and Bertrand, have been

[11] Newbery[52] question whether the strategies of the firms would change significantly if they were forced to supply a step-function instead of the assumed smooth supply function.

used to model price determination in the Nordic electricity pool, Nord Pool. Despite the obvious simplifications, these models are well established and they are easily applicable. The potentially important cases of existence of competitive fringe, and/or cases when there are transmission constraints are examples of applications for which the supply-function model is difficult to apply to[12]. Also, while these are simpler models, their numerical solutions allow more realistic demand and other market specifications than, say, the SF-model where linear demand is often assumed.

Andersson & Bergman [6] modelled the Swedish electricity market price determination using a numerically solved Cournot equilibrium[13] model. The model was calibrated using exogenous mark-ups for the nine largest Swedish generators and a competitive fringe using 1991 data for the production and capacities. This 'base case' equilibrium (1991 equilibrium) was characterised with total output of 142.5 TWh and price of FIM 135 per MWh. The price elasticity of demand was assumed to be -0.3. The authors solved both the Cournot and the competitive cases. The Cournot equilibrium price was FIM 183 per MWh while the competitive price level was FIM 113.25 per MWh. The high price level in the Cournot equilibrium was due to restriction of output by the largest generating company, VAT. The authors also analysed equilibrium prices when the largest company was split into two equal sized companies. The Cournot equilibrium price in this

[12] The SF-model assumes that the slope of the demand does not change over time or levels. Fringe or transmission congestion introduces a 'kink' into the demand at points where these constraints become binding.

[13] More precisely Cournot-Nash equilibrium

case was FIM 129 per MWh[14]. Sensitivity analysis with respect to the price elasticity showed that with more elastic demand (elasticity of -0.6) the Cournot equilibrium with the original market structure resulted in a price of FIM 146.25 per MWh.

Andersson [7], and Andersson et al. [5] analysed electricity price determination in the unified Norwegian-Swedish electricity market, capturing competition in the integrated Nord Pool. The model was basically the same as that of Andersson & Bergman [6], except now there were two integrated price regions. The largest firms from Norway and Sweden were included as Cournot competitors and the rest were aggregated as the competitive fringe. The results indicated that under free trade between the regions the Cournot equilibrium price, FIM 130.5 per MWh, was close to the competitive one. Integration of the two markets seemed to have a favorable effect upon competition. In Autarky the Cournot equilibrium prices were FIM 183.75 per MWh (Sweden) and FIM 126 per MWh (Norway). In comparison the Autarky competitive price levels were FIM 113 per MWh and FIM 120 per MWh in Sweden and Norway respectively. The relatively low Cournot equilibrium price for Norway reflects the fact that it has the most competitive market structure (in terms of market concentration) of the three Nordic countries. The study also indicated strong intra-industry trade pattern under the Cournot case, which is what the trade literature predicts (see Brander[21], Brander and Krugman [21]).Total sales of electricity from Sweden to Norway amounted to 53.1 TWh and total Norwegian exports to Sweden 53.8 TWh. The

[14]Assuming FIM/SEK exchange rate of 0.75

net flow was thus only 0.7 TWh and the transmission capacity (assumed to be 5 TWh) did not become congested.

Borenstein et al.[18] used the Cournot model to analyse price formation in the Californian electricity markets. The authors formulated the residual demand faced by the Cournot firms for many different market demand levels. The level of demand matters for the use of market power. The Cournot equilibrium was solved iteratively for the different levels of the demand using grid-search method.

The authors found that with the generation concentration that prevailed in 1997 in the Californian markets, there was significant potential for the use of market power in times of high demand. When many smaller firms are close to their generating capacity the other firms can profitably reduce their output, knowing that the capacity-constrained firms cannot respond with increased output. In this situation the largest firms are withholding production, and de facto reducing their market share. Use of concentration indices would not therefore account for the increased price-cost margins.

Borenstein et al. [19] analysed a within two-firm two-node setting how the capacity of the transmission line connecting the nodes can affect the nature of the Cournot equilibrium. If the line capacity is small[15] then one of the firms may find it profitable to allow imports by the other firm to the limit the line allows and serve the rest of its market. The authors found in simulations that a small increase in line capacity can bring about large output increases.

[15] There is a threshold capacity, above which the two markets become effectively merged.

1.5.2 Efficiency studies on generation and distribution

The other theme of this monograph deals with the measurement of efficiency of Finnish generation and distribution companies during a deregulation period. Both deregulation and privatisation are, in general, policy issues where measurements of efficiency have been widely used to quantify changes that are predicted qualitatively by theory. Formal definitions of efficiency and productivity can be found in chapter 4. The reviews below concentrate on applications of efficiency measurements studies in electricity markets alone. For general literature reviews on the methods and applications see Seiford and Thrall[99], Pollit [94], and Charnes et al. [28].

1.5.2.1 Efficiency studies on generation

The earliest efficiency studies on the electricity sector include those of Atkinson and Halvorsen [10] and Joskow and Scmalensee [68], which analysed the efficiency of US electricity generation using the cost function approach. The main focus in these studies was to analyse the effect of ownership structure on productive efficiency. Little evidence emerged of significant differences in allocative efficiency between publicly-owned and privately-owned electric utilities.

Färe et al. [46], Weyman-Jones [116] and Hjalmarsson and Veiderpass [61] applied the non-parametric Data Envelopment Analysis (DEA) method to study electricity supply industry performance. The latter two studies analysed the UK and Swedish distribution sectors respectively. Färe et al. [46] analysed the productive efficiency of US electricity generation. They decomposed technical efficiency into measures of pure technical change, scale efficiency and measure of congestion (measuring free disposability of inputs). Scale and congestion measures indicated a 95 percent efficiency level while the pure technical change component averaged approximately 83 percent of potential.

In a more recent study, Yunos and Hawdon [123] analysed technical efficiency and productivity using an international sample of 26 electric utilities for 1987. Production technology was assumed to be constant returns to scale technology with four inputs and one output (electricity). The inputs were: installed capacity, labour, total system losses and the public sector capacity factor. The latter factor was used to take into account intensity of use of the capital equipment under public sector control. System losses were included as input to account for different standards of maintenance and operation of different systems. The results indicated a wide variation of technical efficiency between countries. The lowest value of 0.48 was for Syria, indicating only 48 % efficiency relative to the efficient frontier. The authors could not find systematic evidence of public ownership being an impediment to efficiency.

Pollit [94] used four different methods of efficiency measurement and a sample of publicly owned and privately owned electric power plants. The sample consisted of 768 thermal electricity power plants operating in 14 countries in 1989. The plants were subdivided into four categories according to the load factor: base-load, two intermediate loads, and peak-load plants. The data consisted of four variables: one output and three inputs - capital , labour and fuel. Capital was measured and installed capacity. The null hypothesis of no difference in technical efficiency between publicly and privately owned generators was not rejected with any of the four methodologies employed. The results also revealed a relatively high correlation between the relative efficiency rankings produced by the different techniques.

Chapter 4 analyses technical efficiency and productivity change of the Finnish electricity generation using a panel data of roughly 30 thermal plants for the period of 1994-1996. A best practise frontier against which production units are compared was obtained with the DEA-method. Malmquist indexes were solved for the two subperiods: 1994/95 and 1995/96. Sample distributions for the means of the Malmquist indices were simulated using bootstrap method suggested by Atkinson and Wilson [11].

1.5.2.2 Efficiency studies on electricity distribution

The introduction of competition in electricity sales and generation has also increased interest in developing more efficient regulation of the distribution and transmission sectors, which are natural monopolies. The tendency has been to change from rate of return regulation towards more incentive-based regulation, which has promoted interest in assessing the performance of distribution and grid companies.

The increased interest is reflected in a growing number of studies analysing efficiency and/or productivity of electricity distribution sectors, especially for countries where electricity market deregulation has already taken place. In a recent literature review by London Economics, 18 efficiency studies on electricity distribution sector were reviewed[16]. All models were formulated in input-oriented form, which reflects the nature of the electricity distribution business. Output is treated as given and managers control the use of inputs in order to improve efficiency.

Kittelsen [70] measured the technical efficiency of Norwegian electricity distribution in 1991 and tested different model specifications for the DEA-model. Kittelsen used a stepwise approach to solve efficient frontier and technical efficiencies Different model specifications were considered by either introducing new variables or disaggregating existing ones. Different tests of significance of changes in the means of the technical efficiency scores were used to determine an appropriate model structure.

Based on four statistical tests Kittelsen concluded that a model with three outputs (distance index, energy delivered and number of customers) and four inputs (labour hours, energy loss, capital and goods and services) would contain sufficient information for technical efficiency measurement.

The work by Kittelsen provides important information, especially on variable choice, for other applications of performance studies on the Norwegian distribution sector. Førsund and Kittelsen [42] studied total factor productivity development in Norway between 1983 and 1989 to give an indication of the productivity change before deregulation of the Norwegian electricity market. The model the authors used is based on Kittelsen [70]. Productivity was measured by Malmquist index. The average value for the index was 1.12, which corresponds

[16] See http://www.londecon.co.uk/pubs/default.htm

to 1.9 % annual productivity growth. The efficiency component of the index was 1.006, indicating 0.6 % efficiency improvement and the technical change component was 1.108 indicating 10.8 % increase in this component.

Karlsson [69] analysed 194 Norwegian distribution companies' data for 1994 and 1995 using a model basically the same as that employed by Førsund and Kittelsen [42], though Karlsson used line length instead of the distance index to model the geographical area of the distribution. Average values for the technical efficiency scores were 0.78 in 1994 and 0.83 in 1995 under constant returns to scale.

According to Karlsson [69] an average of 22 % input reduction was needed to achieve technical efficiency in 1994, and 17 % in 1995. The Malmquist productivity change for 1994-1995 showed 5 % increase in total productivity, of which 12 % was an increase in the frontier shift component and 6 % a fall in the efficiency component.

Langset and Torgersen [77] had earlier used a similar model to Karlsson in a study for the Norwegian regulator, Norges Vassdrags og Energiverk (NVE). The NVE study also included prices, and cost efficiency was calculated for all the country's 198 distribution companies using 1995 data. Results indicated an average cost efficiency of 79 %, meaning that on average costs should be cut by 21 % to achieve minimum costs.

Hjalmarsson and Veiderpass [61][62] studied the performance of the Swedish distribution sector during the period 1970-1986. They used a model of four outputs (low and high voltage energy delivery and customers) and four inputs (hours worked, high and low voltage line length and transformer capacity). Productivity growth was fairly rapid in the distribution sector: average growth over the 17-year period was 5%. The main reason for the rapid growth was increased returns to network density, i.e. an increasing amount of energy delivered with a given network capacity. The authors found that productivity growth was considerably lower in the sub-period of 1978-1986, during which the average growth rate was about 2.5 %. The increase seemed to be larger in urban than in rural utilities. The authors categorised all distribution areas with over 5000 inhabitants as urban. Comparison of technical efficiencies between different ownership types revealed that in 1986, for example, state-owned companies and municipal utilities had the highest efficiency scores.

Pollitt [94] focused on the effect of ownership on the performance of electricity utilities. For an analysis of various efficiency measures on electricity distribution he utilised pooled data on the UK and US distribution companies. The total sample was divided into three groups according to number of employees: large firms with over 1000 employees, medium sized firms with 300-1000 employees and small firms with less than 300 employees. The presumption was that the nature of production differs significantly between different sized firms. The division of the sample into these groups was done to eliminate excessive variation in the DEA scores. Efficiency was measured by both an input oriented DEA model and a cost function (using OLS). Pollit described distribution production as the delivery of energy to various nodes to produce outputs differentiated by quantity of energy, location, voltage and the load profile. The output variables used were number of customers, residential sales, non-residential sales, service area and maximum demand. The input variables were the number of employees, circuit length and transformer capacity. Data on distribution losses were not included as they were not available.

The efficiency results did not show statistically significant differences in technical efficiency between publicly owned and privately owned distribution utilities.

1.6 The structure of the Nordic electricity markets

This section outlines the main characteristics of the Finnish, Norwegian and Swedish electricity markets.

1.6.1 Finnish electricity market

Finland's electricity procurement is highly diversified. Total generation in 1994 was 62,18 TWh, of which 30 % came from nuclear power, 20 % from hydro power, 30 % from co-generation (CHP) and 20 % from conventional condensing power. Imports from Russia (5 TWh), Sweden (1.6 TWh) and Norway (0.002 TWh) amounted to 9 % (6.602 TWh) of the total electricity procurement. Such a diverse pattern of generation has the obvious advantage of low dependence on a single exogenous factor, such as yearly precipitation level (as is the case in Norway[17]). On the other hand, a fairly large share (over 20 %) of

[17] Although in Norway there are large reservoir capacities that alleviate the problem

Finnish generation uses imported coal and natural gas, and is therefore subject to possible cost shocks if the fuel prices rise considerably. Another distinctive feature of electricity procurement is the large share of co-generation of heat and electricity (CHP). In utilising and developing co-generation techniques Finland is among the world leaders.

Current total generation capacity is about 14.9 GW. Total demand is forecast to reach 92 TWh by 2010. This is roughly equivalent to a 2 percent annual increase in consumption of electricity.

The total electricity demand is divided as follows: industry 55.1 % , households 23.1 %, agriculture 3.9 %, service sector 11.2 %, and public sector 6.7 % . Transmission losses are about 4 % of the total consumption. A short review of different types of electricity generation in Finland is presented next. For an interesting and detailed account of the development of the electricity sector in Finland see Myllyntaus [86].

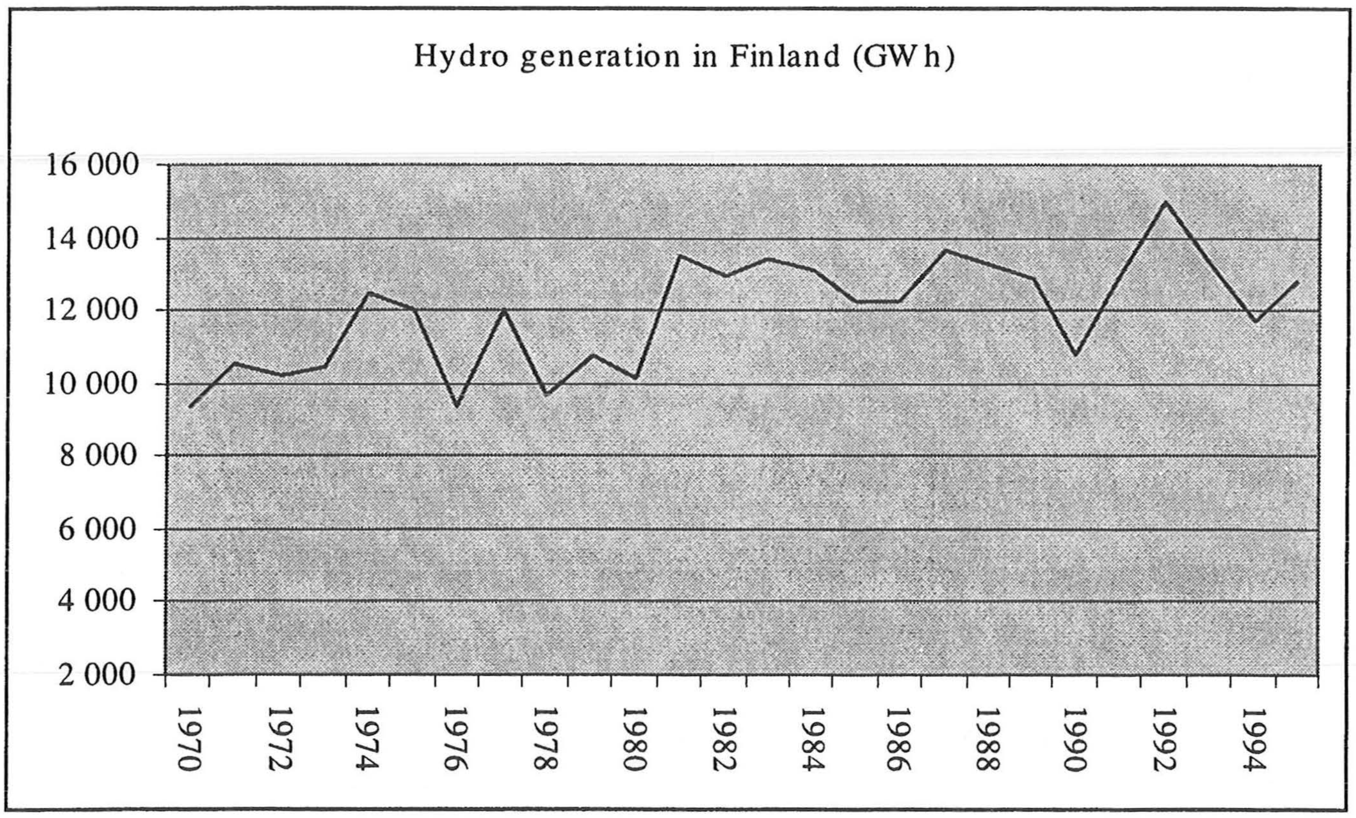
1.6.2 Structure of Finnish electricity generation

1.6.2.1 Hydro power

Hydro power was for decades the dominant electricity generation technique in Finland; in the 1950s hydro power accounted for over 90 % of total generation. This share has steadily fallen and by the 1990s it was around a fifth of total generation, in 1994 total hydro capacity was about 2700 MW, i.e. 19 % of total capacity. Despite estimates of current unharnessed hydro capacity equivalent to about 8 TWh of electricity generation per year, only about 25 percent of this is feasible (due to various environmental restrictions).

Finland's hydro plants are characterised by fairly low capacities due to fairly low geographical profiles of the sites. A large degree of seasonal variation is common to hydro generation, and in Finland the natural flows vary about 50% around the yearly averages. However, a large number of lakes (some artificial) makes the control of hydro power relatively easy. The controllability of hydro power means that it can be used to meet any changes in demand for electricity quickly. Hydro-electricity generators can be stopped and started in minutes. In addition to diurnal variation hydro power can also be used to serve yearly variations in load, especially during the winter season when load reaches peak levels. Figure 1.3 shows hydro generation levels in Finland in 1970-1995.

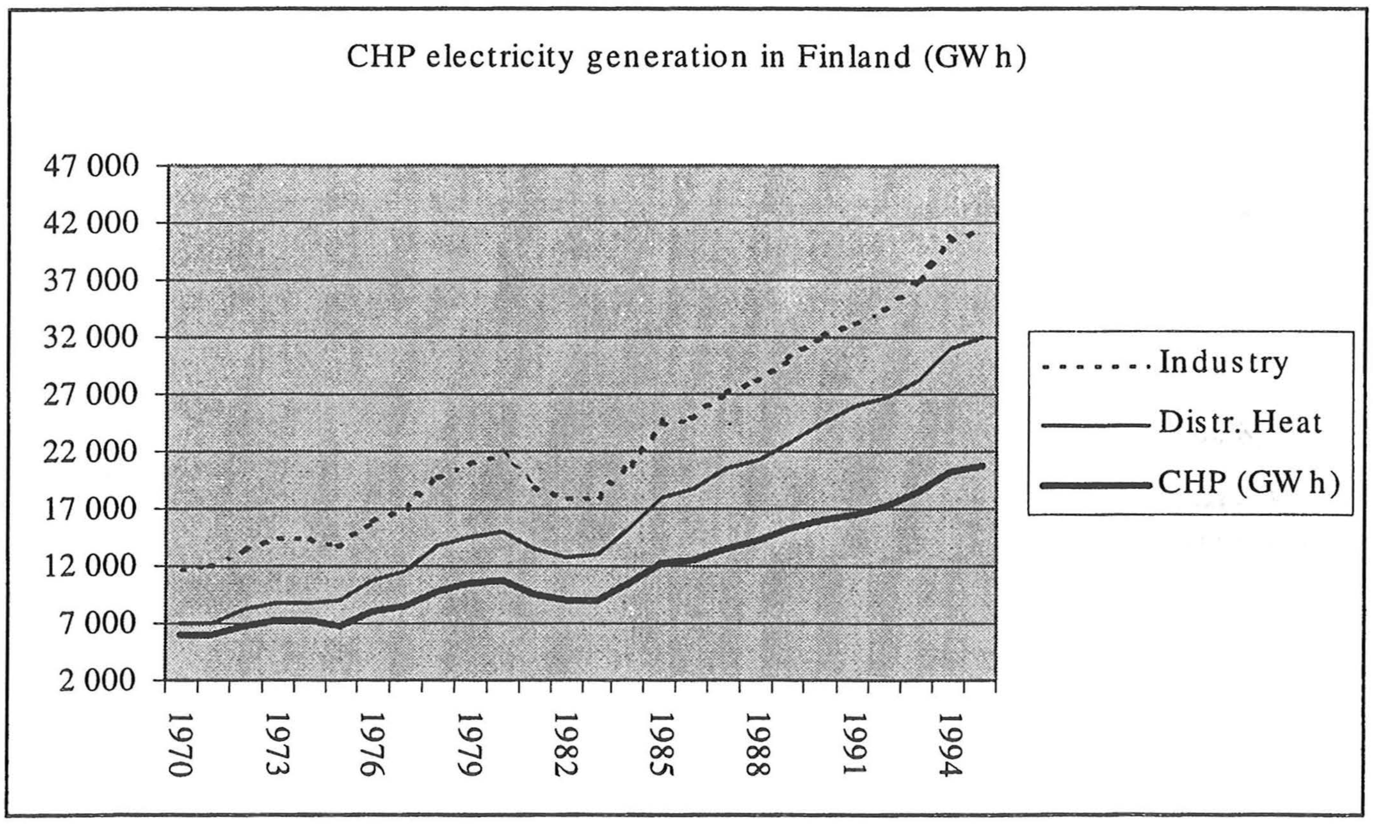
Figure 1.3. Hydro generation in Finland 1970-1995



Hydro power is characterised by high fixed costs (hydro plants are expensive to build) but very low marginal costs. For this reason it is economical to use hydro capacity as base-load capacity, in addition to serving demand peaks.

1.6.2.2 Combined heat and electricity generation Finland's energy efficiency is among the highest in the world. One contributing factor is the large share of combined heat and electricity generation (CHP) of the total power generation. CHP electricity is commonly generated by a backpressure technique, resulting in overall efficiency ratios of about 85-90 %.

Figure 1.4. CHP generation in Finland 1970-1995



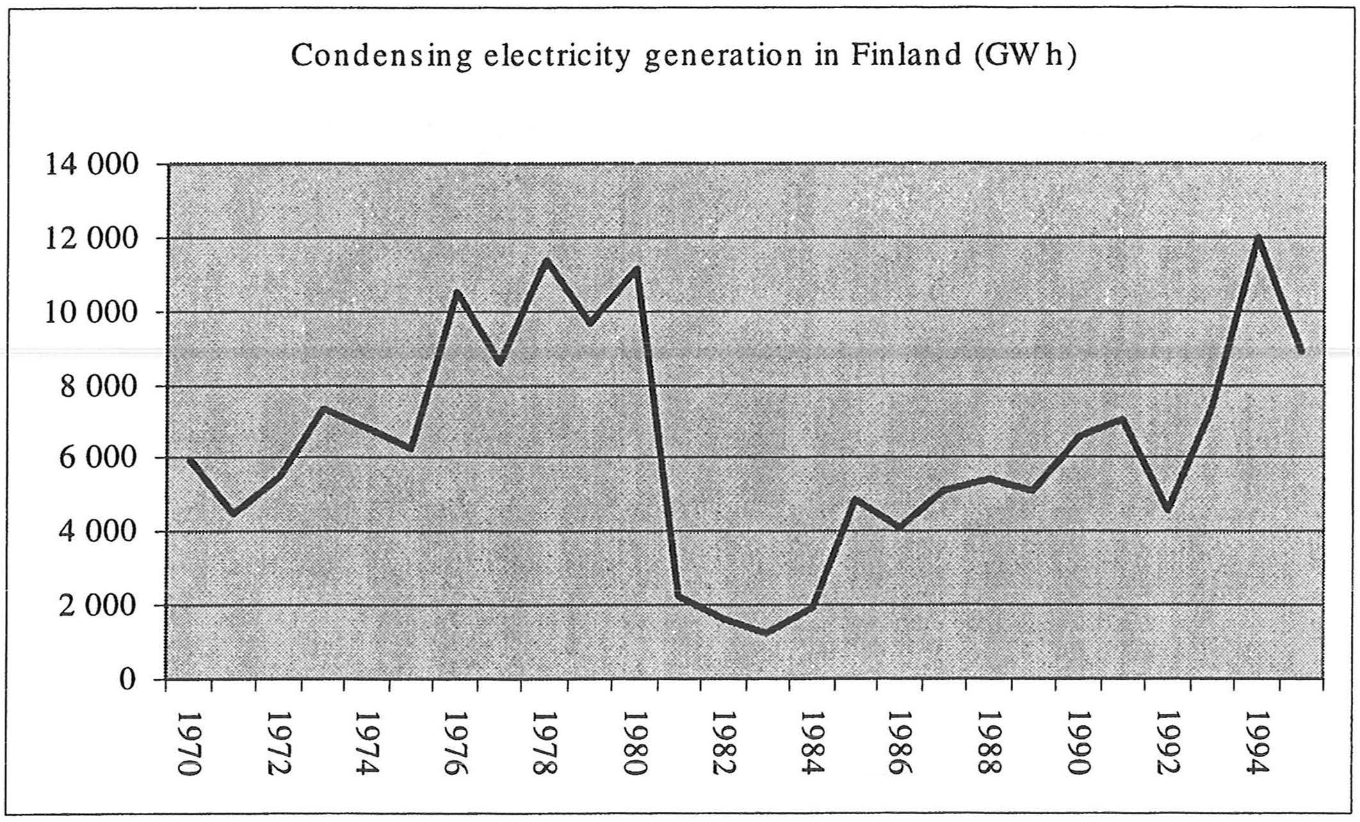
In Finland CHP generation is divided between energy-intensive industry and district heating. Industry based generation is especially important in the pulp and paper industries, where heat is required in the production processes. Figure 1.4. shows that industrial CHP was

9.4 TWh in 1994, which is about 15 % of total electricity supply for that year.

1.6.2.3 Conventional condensing

Conventional condensing units in Finland are typically fairly large (200-1000 MW) coal-based plants located on the west coast. Total condensing capacity in 1994 was about 3500 MW. In addition to the large coal-based plants, there are a number of gas turbine plants servicing peak-load demand. These are typically small in size (10-60 MW) and the total capacity amounted to about 800 MW in 1994.

Figure 1.5. Conventional condensing generation in Finland 1970-1995



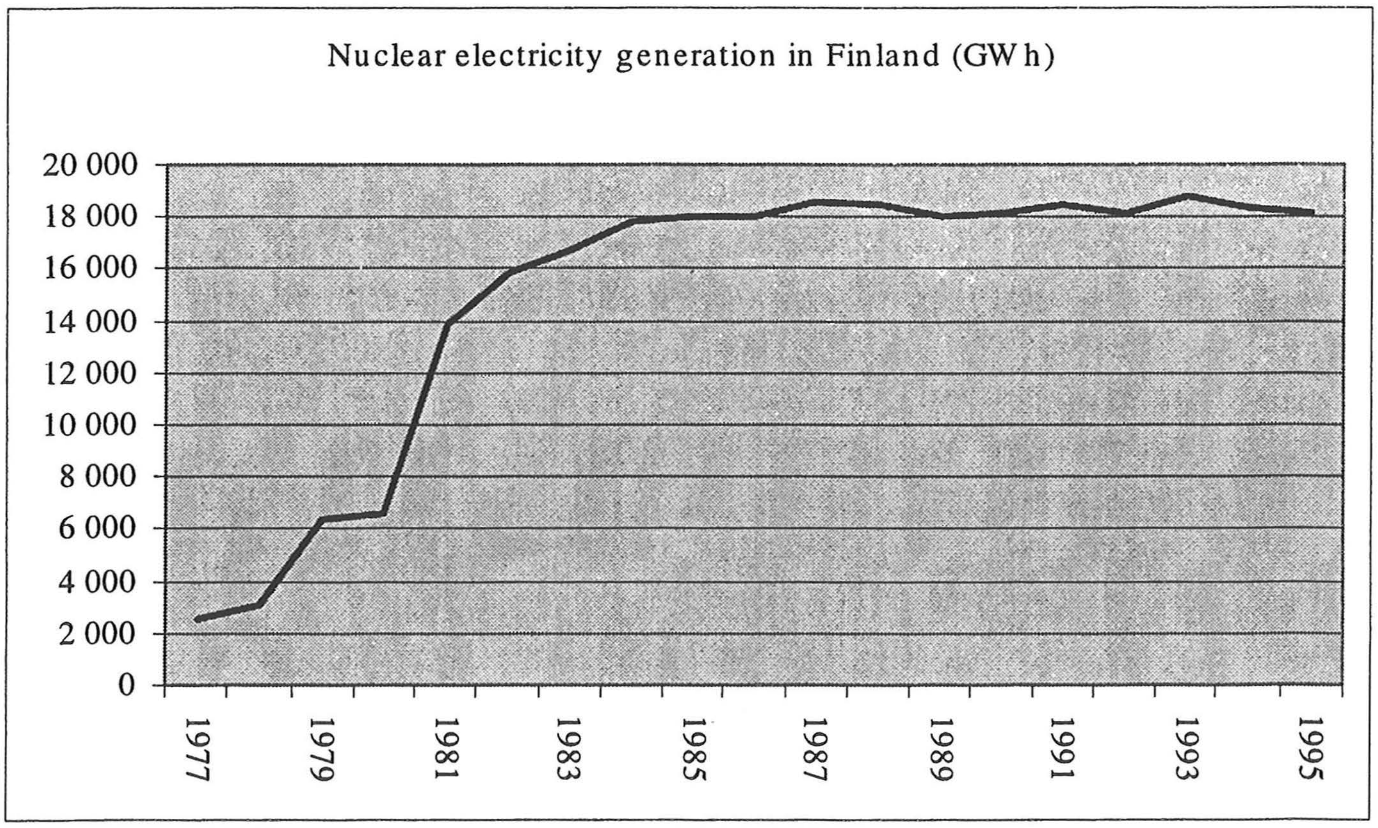
Investments in large coal plants during the 1980s and 1990s increased the total capacity of generation. Coal-based generation is a mid-merit capacity in terms of optimal dispatch as these have relatively high marginal cost. Estimates of the marginal cost of condensing generation are about 9 Finnish pennies per kWh.

Gas-turbine plants are low-fixed cost high-variable cost plants used during peak load periods.

1.6.2.4 Nuclear power

Finland's first nuclear plant was built in 1977 in Loviisa. Currently there are two nuclear plants each with two units; the state owned Loviisa plant and an industry owned Olkiluoto plant. The total capacity of these plants is over 2700 MW.

Figure 1.6. Nuclear generation in Finland 1977-1995

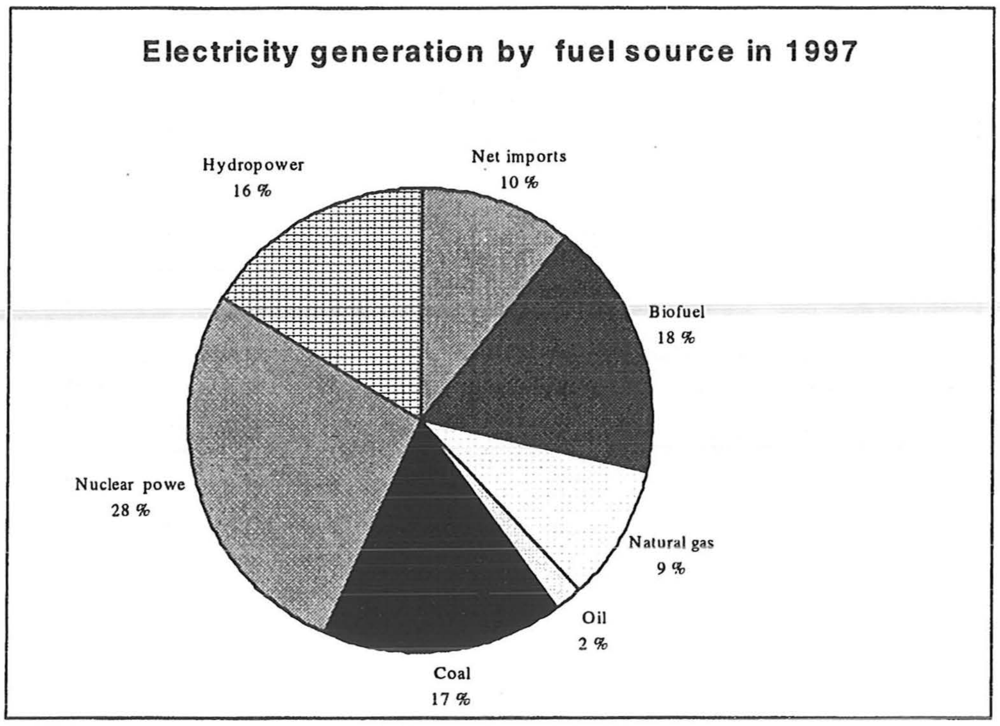


The share of nuclear power has been fairly steady since the mid-1980s. Nuclear power generation resembles hydro power in that it has very high fixed costs and relatively low variable costs. Investment costs account for over 70 % of all generation costs. In addition there are waste disposal costs that according to Pirilä and Lehtilä are about 0.3-0.35 p/kWh. The marginal cost of generation is estimated to be 4 p / kWh.

Finland's only indigenous resources are hydropower, peat, wood and wood waste. All oil, coal and natural gas are imported. The most common fuel in thermal power plants is hard coal, which is used by the largest condensing plants. Gas-turbine plants use light oil or industrial petrol.

In industrial CHP generation waste fuels such as waste wood are important fuels. The district heating CHP plants use mainly hard coal, though in Oulu, Kuopio and Tampere these plants use also peat as their main fuel.

Figure 1.7. electricity generation by fuel source



1.6.3 Networks

Before deregulation, the national grid was divided between two sections according to its ownership. The state owned company IVO operated and owned the main part of the grid, while in the western part of Finland the remaining 20 % or so was in the hands of an industry owned company PVO. This arrangement is quite unique, as transmission is normally the monopoly of one company. The PVO grid was built by large scale industry in order to exercise control over the pricing of the network services.

The national grid consists mainly of 400 kV lines. There are also some 220 kV and 110 kV lines in the grid network, which covers the whole of Finland. In November 1996 a new grid company, Fingrid, started to operate the national grid. The company bought all the high voltage lines from IVO and PVO. Fingrid has the system responsibility and it applies point tariffs of transmission. Ownership is divided (by voting shares) between IVO (30%), the PVO (30 %), institutional owners (15%) and the state (15%).

1.6.4 Electricity market Act

The Finnish Electricity Market Act came into force in June 1995, first opening up the 500 kW customer market. The second and final phase of the market deregulation began on 1.1.1997 when all customers became entitled to choose their suppliers. Transmission and distribution of electricity is regulated by the new authority, The Electricity Market Authority, which is an independent expert body subordinate to the

Ministry of Trade and Industry.

Finland's market reform model resembled that of the non-voluntary pool model, as a bilateral contract market and a pool, which was based on both demand and supply bidding, were active simultaneously. The pool, EL-EX, began operating in August 1996 and accounted initially for only about 5 % of the country's total electricity trade in 1996. Despite its small share of trade the quoted spot prices provided a useful point of comparison for bilateral contracts. There has been fairly rapid convergence of the Finnish Pool with the Nordic electricity exchange, the Nord pool A.S.A. As of 3.6.1998 EL-EX started to operate as an official representative of the Norwegian-Swedish joint spot market Nord Pool A.S.A. In May 1998 the Swedish Svenska Kraftnät became a major owner of EL-EX with a 50 % share. Currently Nord Pool includes Finland as a market place for electricity trading.

Deregulation followed a rapid rationalisation process among Finnish electricity companies. Some companies merged and the largest company IVO has increased its share of the retail market by buying distribution companies. IVO (currently Fortum) also bought the majority share of Sweden's Gullspång and formed a joint company, Birka Energi, with the Stockholm Energi. There have even been talks of a merger of the largest Swedish company Vattenfall and Fortum, which have not yet realised.

1.6.5 Market concentration

A common view is that market power is highly correlated with the degree of market concentration. A firm with a very small market share would hardly restrict its output in order to raise the market price as the demand would have to adjust only a little, and hence the price would rise only slightly. Secondly, when the majority of demand is served by others, the firm would find that others would increase their output by the amount which replaces the small firm's reduced output, without driving up their costs very much. Therefore a firm with a very small market share is likely to see demand as very price elastic. A firm with a considerable market share, on the other hand, may realise that other firms have difficulties in compensating for its output reduction. In electricity markets this behaviour becomes relevant, especially during high demand periods.

As pointed out in Borenstein et al. [19] the connection between market share and market power should not be, however, over-emphasized. Even a firm with a small market share may exert considerable market power if the producers' supply elasticity is very low (especially during peak demand time).

1.6.5.1 Measuring the degree of concentration

In the early industrial organisation literature the so-called structure-conduct- performance paradigm [18] was influential. According to this view the market structure (number of firms, entry barriers etc.) determines the conduct of the firms (pricing, investment etc.), which in turn determines the performance (technical and allocative efficiency, technological progress etc.). This flow of causation implicitly assumes

[18]pioneered by researchers of Harvard University, especially E.Mason in 1930s and J. Bain in the 1950s and 1960s

that the structure is immutable. Recent work has shifted the focus from the analysis of dependence of conduct and performance upon structure to the determinants of the market structure.

Although the degree of market concentration and the potential for using market power may not be directly related, concentration indices are still used as 'first screen' for potential for market power. In the US, for example, the regulator, FERC, uses concentration measures as a screening tool.

The degree of concentration in the Finnish electricity sales market is measured with the Herfindahl-Hirschmann (HH) concentration index, which is defined as the sum of the square of market shares of firms in the industry:

$$H = s_1^2 + s_2^2 + ... + s_n^2 \tag{1}$$

H is negatively correlated with number of firms in the industry. When the number of firms increases their market shares fall and the value of H falls. In the extreme case of a perfect competition H becomes zero. In the case of a monopoly H has the value of one. When firms are symmetric the formula simplifies to $H = \frac{1}{N}$ in the case of N-firm industry. It can be further shown that in this case the industry profit (Π) to revenue (R) ratio can be written as

$$\frac{\Pi}{R} = \frac{H}{\eta}(1 + \mu)$$

where μ is the weighted sum of the conjectural variation terms and η is the price elasticity of demand. This formula emphasizes the old structure-conduct- performance paradigm where the structure of the market (H and η) determine performance (the profit-revenue ratio) via conduct (μ).

Table 1.1 presents the major electricity producers in Finland in 1994. The state owned company Imatran Voima (IVO)[19] is the largest electricity company in the Finnish electricity market. IVO's share is about half of total generation in Finland. The other large company is Pohjolan Voima (PVO) which is an industry owned group selling most of its electricity to the owners at break-even terms. PVO also sells electricity to third-parties via its sales organisation, Teollisuuden Myynti Ltd. (PVO). The other larger companies are mainly municipally owned 'city-generators' that are typically CHP generators. The nine largest companies accounted for 88 % of total Finnish electricity generation in 1994.

The sum of squared market shares totals 0.312 and the reciprocal is 3.2 so the market is roughly equivalent to a three equal sized company market according to this measure.

Table 1.1 Major Finnish electricity companies and the generation levels (TWh) in 1994

	HYDRO	CH	COND	NU	GASTUR	sum	Share
IVO	6.536	7.026	5.776	9.733	0.000	29.071	0.468
PV	1.929	4.141	4.450	6.652	0.000	17.172	0.276
Helsinki	0.000	3.000	0.545	0.000	0.000	3.545	0.057
Enso	0.390	1.520	0.000	0.000	0.000	1.910	0.031
Tampere	0.041	1.204	0.047	0.000	0.000	1.292	0.021
Lahti	0.000	0.294	0.083	0.000	0.000	0.377	0.006
Espo	0.000	0.696	0.000	0.000	0.000	0.696	0.011
Vantaa	0.000	0.615	0.000	0.000	0.000	0.615	0.010
Oulu	0.168	0.389	0.019	0.000	0.000	0.576	0.009
Rest	2.599	1.313	1.064	1.950	0.000	6.926	0.111
Sum	11.663	20.198	11.984	18.335	0.000	62.180	1.000

*Data based on Finnish electricity utilisty statistics 1995

[19] Currently Fortum, after the fusion with state owned oil and chemical company Neste

Rännäri [96] calculated the HH-index for 1995 Finnish data and obtained a value of 0.288. Green and Newbery [52] indicated that if there are at least five equal sized actors in the market, the outcome is close to the competitive one. Rudkevich et al. [97] used a game-theoretic framework and concluded that more than 30 equal sized firms would be required for a competitive outcome.

1.7 Norway

Nordic electricity market restructuring began with the introduction of the Norwegian Electricity Market Act in 1991, which initiated competing in generation and marketing of electricity in Norway. Statkraft, the dominant state-owned electricity company, was re-organised and simultaneously given a degree of independence; while it remained a state-owned company it is now run along commercial lines. Its vertical monopoly structure was split into separate companies: Statkraft SF which is now solely responsible for the generation and sales of electricity, and Statnett SF, which was established as the grid company (controlling 70 % of the high voltage >132 kV lines) and also acts as the system operator. Transmission and distribution remain regulated by the Norwegian Water and Energy Administration (NVE).

A Statnett subsidiary, Statnett Marked, was established to administer the spot market for electricity trading. Statnett Marked formed the basis of a joint Norwegian-Swedish electricity pool, Nord Pool A.S.A, which began operating on 1.1.1996 at the time the Swedish electricity market was deregulated. NordPool is owned and operated on a 50-50 basis by the two grid companies Svenska Kraftnät and Statnett SF. In 1997, the total volume of trade in the Nordpool spot (40.6), futures (42.6) and regulating markets (5.9) was 89.1 TWh, and the spot market trade represented about 20 % of total Norwegian-Swedish electricity consumption. Statnett also runs a real-time market (the regulating market), using it to settle imbalances in real time.

As of 3.6.1998, the Finnish electricity exchange EL-EX began operating as the official representative of Nordpool in Finland. EL-EX products have since been merged with Nordpool's, and its ownership base broadened in May 1998 when the Swedish grid company Svenska Kraftnät purchased a 50 % share. EL-EX was merged with NordPool in 1998. Nordpool organises two markets, Elspot and Eltermin, the latter being the futures and forward market. Elspot is a day-ahead market in which a trading day is divided into 24 hourly markets. Market participants provide separate bids for these 24 hours and the market clears for each of these hours. Each participant provides a schedule of quantities and prices by 12 noon for delivery the following day. The clearing price is determined by 2:00 pm and final prices are determined. A generator can specify a range of prices and quantities with which it buys or sells on the spot market. In addition, a generator can have bilateral contracts on the sale of electricity. In practice there can be different price zones, and NordPool arranges separate Elspot markets for each zone.

Norway's electricity generation is practically all hydro power; in 1994 total electricity generation was 113,5 TWh, of which 112.9 TWh (99.4 %) was hydro generated. The 1994 generation level can be considered as an average yearly generation level. The system has large reservoir capacity, (about 80 TWh) which is able to store water for a number of years. This enables the system to adjust to changes in consumption, but also makes it vulnerable to the single power source, the water supply. 1994 production levels and capacities (equivalent to TWh per year) of the largest Norwegian companies are given in Table 1.2.

Table 12 Major Norwegian electricity companies

	Production	Capacit
Statkraft Sf	31.70	47.50
Norsk Hydro AS	9.40	14.10
Oslo Energi AS	7.80	11.70
Bergenhalvö ens komm.Kr.elsk.	5.40	8.60
Lyse Kraft	5.30	7.90
Trondheim energiverk	3.00	4.50
Hafslund Energi	2.60	4.00
Nord Tröndelag Elverk	2.50	3.70
Skienfjordens Komm Kr.elsk.	2.50	3.70
Vest Adger energiverk	2.30	3.40
Total	72.50	109.10

∗ Data based on the Energy sector + water resources in Norway in 1994" Ministry of Industry and Energy (1995)

The largest company, Statkraft Ltd, provided approximately 30 % of the total production.

1.8 Sweden

The deregulation of the Swedish electricity market commenced in 1991. The largest state owned company Vattenfall was re-organised into an independent generation company, a regional network company and several local network companies. All its operations in the national grid were transferred to a separate grid company, Svenska Kraftnät, which manages the national grid and is responsible for all international links.

Deregulation entailed fundamental changes: production and sale of electricity were completely separated from the transmission and distribution of electricity. The transmission of electricity on the grid was regulated by a new authority, the Grid Authority, which has since been replaced by the Swedish National Energy Administration.

The main points of the new Electricity Act are as follows:

· All grids are to be accessible to all players, who pay a selective tariff for utilizing the grid.

· The selective tariff system means that those who have paid to feed in or take out power at a connection point will obtain access to the entire grid system and the electricity market.

· Grid operations will, from an organizational and accounting point of view, be separated from production and trading.

· Requirements placed on those responsible for grids will be regulated in special licences, grid concessions.

· Those with grid concessions are obligated to connect all who require this to the grid and to transmit power under reasonable and non-discriminatory terms and conditions.

· A new grid authority, nowadays a department of the Swedish National Energy Administration, monitors grid services, concessions, tariffs and other transmission terms and conditions.

· Svenska Kraftnät has the system responsibility

· Grid owners are responsible for measurements and reports within their areas.

· A five-year supply concession was introduced, involving rights and liabilities for the holder.

The total amount of electricity generated in 1994 was 137,65 TWh, 42 % of which was hydro power, 51 % nuclear power, and the remaining 7 % fossil fuel based generation. Table 1.3 shows that the largest company, Vattenfall, dominates the market with over 50 % market share. Vattenfall is the largest supplier of electricity in the Nordic market (units in TWh).

Table 1.3 Major Swedish electricity companies in 1994

	HYDRO	CHP	COND	NUC	GASTUR	CAPACITY
Vattenfall AB	29.60	1.50	0.00	42.90	0.00	117.90
Sydkraft AB	9.20	1.90	0.00	15.40	0.00	51.00
Stockholm Energi AB	3.50	3.60	1.60	4.60	0.00	18.20
Gullspångs Kraft AB	3.70	0.70	0.00	4.00	0.00	13.40
Stora Kraft AB	3.60	0.20	0.00	1.70	0.00	10.30
Skellefteå Kraft AB	1.80	0.10	0.00	0.50	0.00	3.40
AB Skandinaviska Elverl	0.00	2.20	0.00	0.00	0.00	4.10
Granige	0.00	1.60	0.00	0.00	0.00	2.10
Total	51.40	11.80	1.60	69.10	0.00	220.40

*Data based on the annual report of the Swedish Power Association 1994 and on the Firms' annual reports

1.9 Nord Pool and Cross-border electricity trade

The actual trade pattern within the Nordic market for 1994 is shown in Table 1.4. Exports from Finland to Norway and Sweden were less than 0.5 TWh, while Sweden exported 1.6 TWh to Finland, and Norway exported 4.4 TWh to Sweden. The existing transmission capacities between these Nordic countries are shown in Table 1.4.

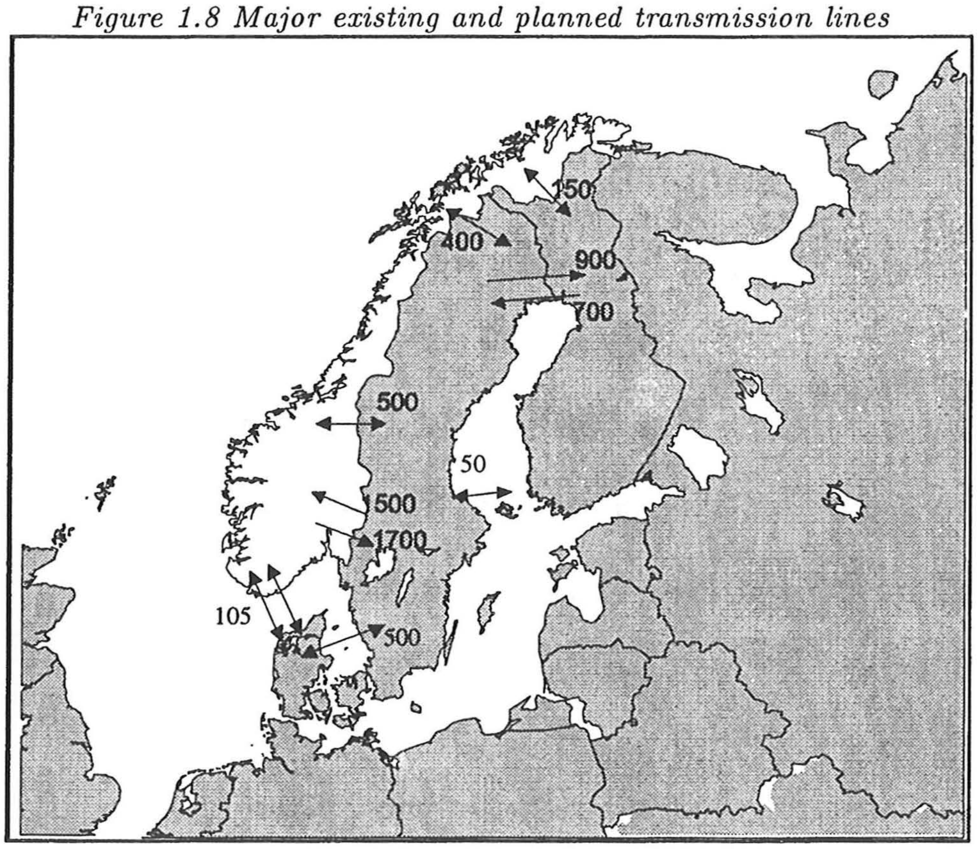
*Table 1.4. Exports and Imports 1994 ,GWh**

	Imports to:		
Exports From:	Finland	Norway	Sweden
Finland	0	291	298
Norway	1	0	4430
Sweden	1664	2850	0

*source: Nordel 1994

The trade flows reflect the fact that 1994 was more or less a normal year in terms of water supply in both countries, with average water supply Norway and Sweden are typically net-exporters of electricity to Finland (and Denmark).

Figure 1.8 Major existing and planned transmission lines



The total transmission capacity from Finland to Sweden is about 1300 MW, which is equivalent to an annual maximum of 11 TWh. An additional 200 MW link from Sweden to Finland and a 500 MW link from Finland to Sweden are under construction.

Figure 1.9. presents the monthly spot prices in Nordpool.

Figure 1.9 *Monthly ELSPOT prices in 1998*

Month	Oslo	Stockholm	Helsinki	System
January	119,82	119,33	119,33	119,65
February	107,09	107,06	107,06	107,31
March	95,99	95,64	95,64	95,74
April	89,87	89,18	89,18	89,66
May	77,74	73,35	73,35	78,34
June	86,32	84,51	84,51	85,66
July	50,00	47,89	52,00	49,52
August	35,22	44,41	53,65	38,46
September	53,48	55,41	59,01	55,44
October	72,65	71,40	71,40	72,81
November	97,69	92,22	92,21	98,23
December	101,86	94,26	94,26	100,99
The year	**82,11**	**81,02**	**82,44**	**82,45**

For the model used the Nordic area was simplified into a two-region (Finland and Nordpool) two-node market. It was assumed that a total of 15 TWh net trade can occur between the two regions.

Table 1.5 reports the Herfindahl-Hirschman (H-H) indexes and their reciprocals for the combined Norwegian-Swedish market (No-Swe), the Finnish market (Fin) and for the unified Norwegian-Swedish-Finnish market (All).

Table 1.5 Market concentration

	No+Swe	Fin	All
H-H index	0.18	0.30	0.13
Reciprocal of the H-H	5.52	3.35	7.62

According to the HH-index the combined Norwegian and Swedish market (No+Swe) is equivalent to one with 5.52 equal-sized companies, while the Finnish market alone is equivalent to one with 3.35

equal-sized companies. Combined, the market concentration is reduced further to one with nearly eight equal-sized companies.

2 The Finnish electricity market: an analysis of spot-market equilibria

This chapter contains an analysis of competition in the Finnish electricity spot market using one-region oligopoly models. The structure of the basic model used to analyse the market outcomes is presented below. This is followed by a presentation of different oligopoly models, after which numerical solutions (using Finnish electricity market data) to some of these are given.

2.1 The model

The model used for numerical simulations is a standard static partial equilibrium oligopoly model. The total demand for electricity, D_E, is represented with a constant price elasticity of demand format

$$D_E = D_0 \left(\frac{P_E}{P_0} \right)^{\varepsilon} \tag{2}$$

where D_0 is the total load level in Finland at initial equilibrium[20], P_E denotes the price of electricity (this can be interpreted as the average yearly spot price of electricity), P_0 is the reference price level and $\varepsilon = \frac{\partial X}{\partial P_E} \frac{P_E}{X}$ denotes the price elasticity of the demand. Total supply of electricity, S_E, is given by a sum of all domestic firms' generation, $\sum_{f=1}^{F} X_f$, and total imports of electricity, M

[20]The model is calibrated for 1994 data, that is, parameters are chosen so that the 1994 average price and outputs are obtained as a solution to the model

$$S_E = \sum_{f=1}^{F} X_f + M \tag{3}$$

The market equilibrium condition, equality of total supply and total demand of electricity, is given by

$$\sum_{f=1}^{F} X_f + M = D_0 \left(\frac{P_E}{P_0}\right)^{\varepsilon} \tag{4}$$

Solving this for the price of electricity gives the inverse demand function

$$P_F = P_0 \left(\frac{\sum_{f=1}^{F} X_f + M}{D_0}\right)^{\frac{1}{\varepsilon}} \tag{5}$$

Each firm f minimises costs of generation for a given estimated level of load. The cost minimising use of generation plants is determined as

$$\begin{aligned} &\min \sum_i C_{fi} X_{fi} \\ &s.t. \\ &X_{fi} \leq K_{fi} \\ &X_f \leq \textstyle\sum_i X_{fi} \end{aligned} \tag{6}$$

The generation cost of plant i is specified as the sum of firm-independent generation cost, c_i, and the shadow price of capital, λ_{fi}, that is determined from the above generation capacity constraint, $X_{fi} \leq K_{fi}$. Maximum capacities, K_{fi}, for each plant were calculated from the maximum power data (MW) multiplied by 8700 (nearly maximum yearly operation).

The following estimates[21] were used for the generation type-specific

[21] see Energia-Ekono[36] for detailed calculations of generation costs, including investment costs

costs (FIM per MWh): Hydro (10), CHP (50), NUC (40), Condensing (90) & PEAK (150).

The first order condition for the firm's cost minimisation is given by

$$\begin{aligned} \mu_{\mathrm{f}} - c_i - \lambda_{fi} &\leq 0 \\ X_{fi}\,(\,\mu_{\mathrm{f}} - c_i - \lambda_{fi}) &= 0 \\ X_{fi} - K_{fi} &\leq 0 \\ \lambda_{fi}\,(X_{fi} - K_{fi}) &= 0 \end{aligned} \tag{7}$$

The Lagrange multipliers, λ_{fi} and μ_f, associated with the constraints are interpreted as the shadow price of an extra unit of capacity (λ_{fi}) and the marginal cost of generation for the firm f (μ_f). Each plant's marginal cost is the sum of the generation cost and the capacity cost, $C_{fi} = c_i + \lambda_{fi}$.

Electricity companies are assumed to maximise their profits. In the Cournot case the generators compete on quantities without taking into account others' possible retaliation to their output decision. Profits are given by

$$\Pi_F = X_F \times P_F - C_F \times X_F \tag{8}$$

where X_F is output sold to the domestic market by the firm F and is the marginal cost. P_F is the inverse demand for electricity in Finland. The first order condition for the profit maximisation is given by

$$\frac{\partial \pi_F}{\partial X_F} = P_F + X_F P_F' - C_F \leq 0 \tag{9}$$

where it is assumed that $\frac{\partial X}{\partial X_F} = 1$ (the Cournot assumption) and $P_F' = \frac{\partial P_F}{\partial X_F}$. Imports are determined by the difference between the Finnish and the exogenous import price (assuming for time being enough transmission capacity). The latter may be interpreted as the Russian and/or Nordic price level, determined exogenously. It is assumed, however, that the prices need not be equalised due to transmission losses and other possible transport costs, which are represented by term θ. In the simulations these were assumed to be 0.05 (5%). Imports are determined from

$$\begin{aligned} &P_E - (1+\theta) \times P_M \leq 0 \\ &M\left(P_E - (1+\theta) \times P_M\right) = 0 \end{aligned} \tag{10}$$

where M denotes total volume of imports and P_M denotes the price of imports (set exogenously).

2.1.1 Model solution strategies

There are basically four different methods of solving imperfectly competitive market equilibria. If the number of players and of feasible strategies is small, one could use the *payoff matrix method* which involves enumeration of all combinations of player strategies via different payoffs. The Nash-equilibrium (if any) is the strategy combination that maximises each of the players payoff (given others' move) and from which no-one has an incentive to move from. Another method of computing the equilibrium is to use the *iteration* or *di-*

agonalisation method, which iterates different strategy combinations until no player wants to change their strategies (or the change is very small i.e. within a predetermined range of acceptance). The third method is *direct computation of the equilibrium* by using the equilibrium conditions. This requires solving the Kuhn-Karesh-Tucker (KKT) conditions, which involve both equalities and complementarity conditions. The resulting Mixed Complementarity Problem (MCP, formalised in Section 2) can be solved with GAMS/MILES or GAMS/PATH solvers. This method is applied in the models of Finnish and Nordic electricity market competition below. The fourth computational approach is to use the *optimisation model,* which formalises the market solution as a planner problem that yields the same KKT conditions for the maximum as the equilibrium conditions above.

With perfect competition the above model can be cast as a planning problem in which the equilibrium is found by maximising the sum of producer and consumer surplus. The equilibrium is then represented as a solution to the following maximisation problem:

$$\begin{aligned}
\max W &= \int_0^q \left(P_E\left(s\right) - c\left(s\right)\right) ds \qquad (11)\\
& s.t. \\
X_{fi} - K_{fi} &\leq 0 \\
X_f - \sum\nolimits_i X_{fi} &\leq 0 \\
P_E - (1+\theta) \times P_M &\leq 0 \\
X_f &> 0 \\
X_{fi} &> 0
\end{aligned}$$

where the variables are defined as above. This planning problem produces Pareto-optimal allocation of resources given that the production set is convex and there are no externalities (consumption or production). The solution is equivalent to the perfectly competitive market solution.

In the case of imperfect competition the market solution is no longer Pareto-optimal. Bergstrom and Varian [14] have shown that the Cournot equilibrium, if cast as a planner problem, maximises in fact a mixture of social welfare and profits[22]. In the simple case of symmetric firms the maximand is of the form

$$F(q) = (n-1)W(q) + \pi(q) \tag{12}$$

where $W(q)$ is consumer surplus plus producer surplus, and $\pi(q)$ is industry-wide profits. Thus the Cournot equilibrium maximises a weighted sum of welfare and profits. In comparison to perfect competition an extra weight is put on profits over consumer surplus, especially when n is small.

The approach used in this study is direct computation of the equilibrium by using a Mixed Complementarity Problem (MCP) format, which is especially well-suited for models with imperfect competition. The MCP solution is obtained by solving a nonlinear complementarity problem, which in general form is

[22]In general, a model which can be cast both as a planner problem and as a market equilibrium problem (as a set of equations defining the market solution) is said to be *integrable.* In many cases a model is non-integrable, especially when imperfect competition, taxes, or other market imperfections exist, see Mathiensen [82].

$$
\begin{aligned}
Given &: \quad f : R^n \rightarrow R^n \\
Find &: \quad x \in R^n \\
s.t. \quad f(q) &\geq 0, \quad z^T f(q) = 0
\end{aligned} \tag{13}
$$

In the current application the variable vector z^T would be

$$
z^T = \begin{bmatrix} P_E \\ X_{fi} \\ X_f \\ c_f \\ \lambda_{fi} \\ \mu_f \end{bmatrix}
$$

that is a vector of all endogenous variables. $f(q)$ are equations representing the first order conditions for the profit maximisation and cost minimisation. The model is solved using the GAMS /MCP package and MILES (Mixed Inequality and non-linear Equation Solver) solver.

2.1.2 Calibration

Calibration of the model involves determining a set of parameters and exogenous variables so that the model solution replicates the base year equilibrium. For the calibration the outputs of the firms were fixed at their 1994 generation levels (total 62.247 TWh), and a market price of 160 FIM/MWh was assumed. In contrast to the approach taken by Andersson and Bergman [6], who used exogenous mark-ups to calibrate their model, here the calibration is done via endogenous firm-specific conjectural derivates.

The marginal revenue of a firm i can be written as

$$MR_i = P(Q) - q_i P'(Q)\left(1 + \frac{d\,Q_j}{d\,q_i}\right); i \neq j, \tag{14}$$

where $P'(Q) = \frac{d\,P(Q)}{d\,Q}$. The conjectural derivative, $\frac{d\,Q_j}{d\,q_i}; i \neq j$, is denoted below by $\omega \equiv \frac{d\,Q_j}{d\,q_i}$. A positive value for the derivative indicates that the firm expects its rivals to match its own behaviour, e.g. when a firm reduces its output it expects that others will co-operate to restrict their outputs as well. A negative value of the conjectural derivative indicates that a firm contemplating an output reduction would expect its rivals to expand theirs. A zero value of the conjectural derivative is the Cournot case, where other firms' reaction is assumed to be zero. Other polar cases are $\omega = -1$ which is equivalent to the competitive case, and $\omega = 1$, which is equivalent to the case of perfect co-operation. The conjectural derivatives determine values of the Lerner indexes according to

$$\frac{P(Q) - c_i}{P(Q)} = \frac{(1+\omega)\,s_i}{\varepsilon} \tag{15}$$

where s_i is the market share of firm i, and ε is the price elasticity of the demand.

Table 2.1 shows the values of the Lerner indexes (Lerner), marginal costs (MC), market shares (Share), values of conjectural derivatives (Conjecture) and total electricity generation (Output) in 1994. The equilibrium price was assumed to be 160 FIM/MWh. The marginal costs for each firm are determined from the cost minimising use of power plants, and the marginal cost of a firm is the marginal cost of the most expensive plant employed. Firms with a marginal cost of 90 FIM/MWh use conventional condensing plant as the marginal plant, while firms with a marginal cost of 50 FIM/MWh, use CHP. The calibration variable, conjectural variation, was solved so that the initial year data were the model solution. There was a tendency for it to rise the smaller the firm is, suggesting that smaller firms expect a larger reaction by others to their output changes than larger firms. Total generation capacity in Finland was assumed to be about 90 TWh[23].

Table 2.1. Calibration of the Finnish model

Company	Lerner	MC (FIM/MWh)	Share	Conjecture	Output TWh/year
IVO	0.405	90.000	0.469	0.431	29.071
PVO	0.669	50.000	0.277	1.207	17.172
Helsinki	0.405	90.000	0.057	3.538	3.545
ENSO	0.669	50.000	0.031	10.855	1.910
Tampere	0.405	90.000	0.021	9.707	1.292
Espoo	0.669	50.000	0.011	29.788	0.696
Vantaa	0.669	50.000	0.010	33.711	0.615
Oulu	0.405	90.000	0.009	21.773	0.576
Lahti	0.405	90.000	0.006	33.266	0.377
Fringe	0.405	90.000	0.108	0.000	6.689

The two largest firms , IVO and PVO, control over 70 % of the market share, indicating a fairly concentrated structure. However,

[23]In reality the theoretical maximum capacity is about 120 TWh per year, but this disregards the need for maintenance services and other possible disruptions (and start-up delays).

in an international comparison the market structure is relatively dispersed.

2.2 Partial equilibrium models and numerical solutions

2.2.1 Oligopoly models

Market power is ultimately reflected in the price-cost margin, or Lerner index, $\frac{P-MC}{P}$. An assessment of potential for market power by a concentration measure such as the HH-index may give a biased picture of the degree of competition. For example, if dominant firms strategically withhold output in order to drive the market price up, they in fact reduce their market shares and so the observed market concentration index may indicate a more 'competitive picture' than exists in reality. In other words, a lower degree of concentration can be associated with a higher price-cost margin. The fact that concentration indices depend on historical data means that they fail to take into account any changes in the firms' incentives that may take place due to changes in the market environment. Furthermore, concentration index approach fails to capture the effect of price responsiveness of demand or supply.

Some standard static oligopoly models are presented below. The emphasis is on models that have been applied to deregulated electricity markets.

At the outset it is also worth noting that there is no unified theory of oligopoly but rather a set of models (or games) that have been developed for different industries and circumstances. Also, one should note that since only static oligopoly models are considered below, the issue of how rivals *react* to each other's actions should not be regarded in terms of consecutive moves. A well-known model of oligopoly that includes reactions while retaining the static structure is due to Sweezy [105], who suggested that each firm would expect its rivals to match any price reductions, but not price increases. At the initial price (equilibrium) the demand is more elastic for price increases than for price reductions, and hence the 'kinked' demand curve.

2.2.2 Cournot oligopoly

Cournot [30] provided the first formal theory of oligopoly. Cournot's analysis still remains the benchmark model of oligopoly.

Assume n firms producing a homogeneous good for which an inverse demand is given by $P(Q)$,where P is the market price and $Q = q_1 + q_2 + ..q_n$ is the market supply, defined as the sum of individual firms' outputs.

Costs for firm i are given by $C(q_i) = c_i q_i$ and firm i profits by $\pi_i = P(Q)\, q_i - c_i q_i$. Given a set of choices $\{q_i\}$ the price will adjust so that the market clears. Equilibrium output levels are determined from first order conditions of profit maximisation , $\frac{\partial \pi_i}{\partial q_i} = 0$, for all n which gives the pricing rule

$$\frac{P(Q) - c_i}{P(Q)} = \frac{s_i}{\varepsilon}\ ; i = 1, 2, ..., n \tag{16}$$

where $s_i = \frac{q_i}{Q}$ is the market share, and $\varepsilon = \frac{-P(Q)}{QP'(Q)}$ is the price elasticity of the demand. All firms make their output decisions simultaneously and the equilibrium is a Nash equilibrium[24] in quantities. The Cournot equilibrium can be thought of as a state resulting from a set of self-confirming actions (simultaneous moves) from which no firm would want to deviate. The equilibrium condition implies that price will exceed marginal cost and hence the resulting pricing is not allocatively efficient.

Friedman[43] and Novshek[90] elaborate the conditions for existence of the Cournot equilibrium. Novshek shows that with differentiable and monotonic demand and cost function an equilibrium exists as long as

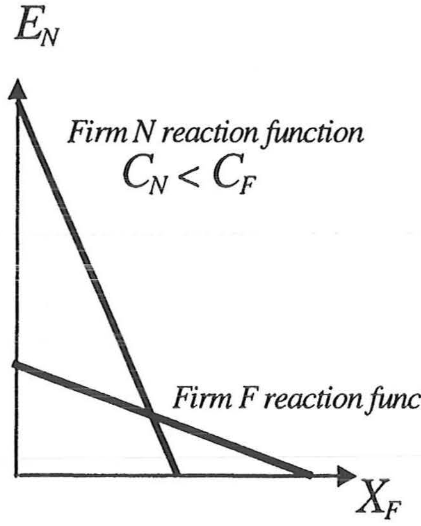
$$P'(Q) + QP''(Q) \leq 0 \tag{17}$$

which is equivalent to the condition that $\frac{\partial^2 \pi_i}{\partial q_i q_j} \leq 0$, i.e. the firm $i's$ marginal revenue must not rise with its rivals' output. When marginal costs are constant the condition is sufficient for uniqueness of the equilibrium.

Figure 2.1 illustrates the Cournot equilibrium for the case of asymmetric duopoly. Costs of firm $i = N, F$ is given by $C(q_i) = c_i q_i$ assuming $c_N < c_F$. The demand is linear $P(Q) = a - bq_1 - bq_2$ and the reaction curve of a firm i is given by $R_i(q_j) = \frac{1}{2}(\Psi_i - q_j); i \neq j$, where $\Psi_i \equiv \frac{a - c_i}{b}$ is the quantity that would be demanded if price were equal to marginal cost. The Cournot-Nash equilibrium is at the intersection of the reaction curves, in the export (E) - domestic sales (X) plane,

[24]The Nash equilibrium is a state where each firm correctly foresees the other firms's choices and all forecasts are mutually consistent

Figure 2..1 Cournot equilibrium



Compared to the symmetric case ($C_N = C_F$) a smaller unit cost for firm N shows up as a shifted reaction curve, away from the origin, and at the equilibrium firm N produces more than firm F. Solving the model for the equilibrium quantities gives

$$q_1^* = \frac{1}{3}\Psi_1 + \frac{1}{3}\frac{c_2 - c_1}{b}$$

and

$$q_2^* = \frac{1}{3}\Psi_1 + \frac{2}{3}\frac{c_2 - c_1}{b}$$

resulting to an equilibrium price of

$$p = c_1 + \frac{1}{3}b\Psi_1 + \frac{1}{3}(c_2 - c_1)$$

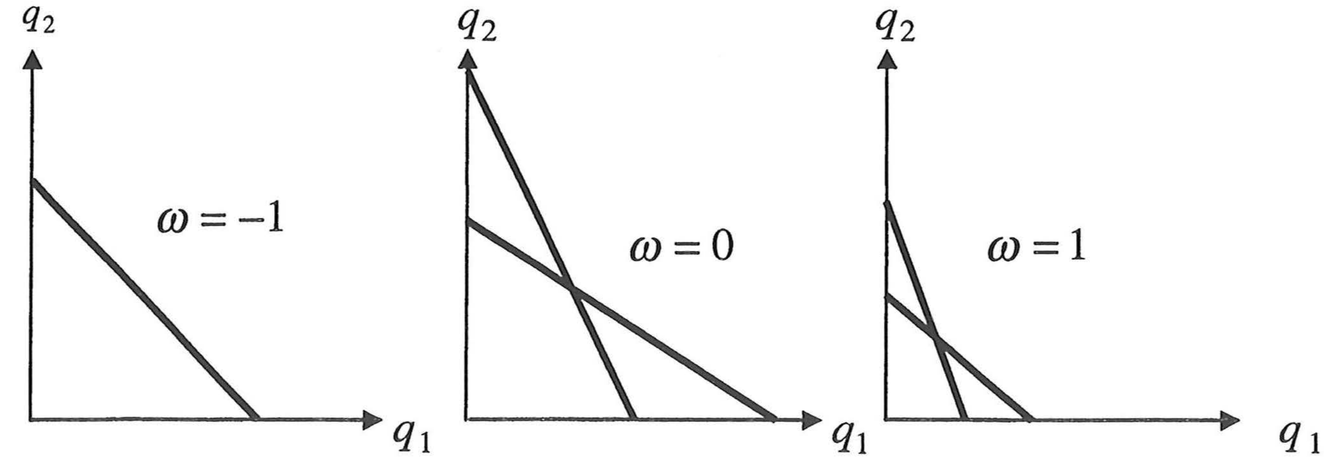
Thus the difference in the costs shows up directly in a difference in the equilibrium sales.

The Cournot model can be criticised for the assumption that other firms' output level is taken as fixed in a market, where in fact interdependence of firms' actions counts. The model has been generalised to a case where the reactions of other firms are not treated as given.

Two different approaches with largely equivalent implications for market performance have been advanced along these lines: a conjectural derivatives approach by Hicks [59], and Bowley[20], and a conjectural elasticity approach by Frisch [44].

When the outputs of other firms are not treated as fixed, the marginal revenue of firm i can be written as $MR_i = P(Q) - q_i \, P'(Q) \left(1 + \frac{d\,Q_j}{d\,q_i}\right)$; $i \neq j$. The conjectural derivative, $\frac{d\,Q_j}{d\,q_i}; i \neq j$, is treated as a constant, so it can be written as $\omega = \frac{d\,Q_j}{d\,q_i}$. A positive value for the derivative indicates that the firm expects its rivals to match its own behaviour. In the case of restricting its output, the firm expects that others will co-operate and restrict their outputs as well. A negative value of the conjectural derivative indicates that a firm contemplating a restriction in its output would expect its rivals to expand output. A zero value indicates the Cournot case. The other polar cases include a common value of -1 for the competitive case and 1 for the case of perfect co-operation.

Figure 2.2



Frisch [44] introduced the concept of conjectural elasticity and assumed the constancy of the elasticity:

$$\alpha_i = \frac{d\log(q_j)}{d\log(q_i)} = \frac{q_i}{q_j}\frac{dq_j}{dq_i}$$

α_i can be interpreted as the percentage change in firm j's output that firm i expects in response to a 1 % change of its own output. If $\alpha_i = 1$ each firm expects that others will follow its output change by an equal percentage amount and in the same direction. When the elasticity value approaches zero, the Cournot case follows. The conjectural elasticity and conjectural derivative measures are related by

$$\omega_i = \alpha_i \sum_{j \neq i} \frac{q_j}{q_i}$$

With non symmetric marginal costs and conjectural elasticities the Lerner index becomes

$$\frac{P(Q) - c_i}{P(Q)} = \frac{\alpha_i + (1 - \alpha_i) s_i}{\varepsilon} \tag{18}$$

A low value of α_i indicates that firm i believes that there is some scope for improving its market share as rivals are not reacting to its output increase by as much proportionately.

In summary, the Cournot equilibrium can be characterised by the following properties:

- the price diverges from marginal revenue

$$p - MR_i = -q_i P'(Q) > 0$$

- the equilibrium lies between the competitive and monopoly equilibria

- the greater the elasticity of the demand the smaller the mark-ups
- the mark-up of firm i is directly proportional to the firm's market share s_i
- with symmetric firms the pricing rule becomes

$$\frac{P(Q) - c}{P(Q)} = \frac{1}{n\,\varepsilon}$$

as the number of firms increases (n increases) the prices will approach marginal cost.

The Cournot equilibrium is not optimal for the firms in the sense that there is a negative externality from firms' maximising their own profit and the aggregate output is higher than in a collusive outcome. Collusion is unstable, however, in the sense that firms will always have an incentive to defect and produce more output, leading to all firms defecting.

Neither does the Cournot solution maximise welfare (as prices are not equal to marginal cost). Bergstrom and Varian [14] showed that the Cournot equilibrium in fact maximises a mixture of social welfare and profits. If gross benefits are defined as the area under the demand curve, $B(Q) = \int_0^Q p(z)\,dz$, and total welfare is the sum of producer and consumer surplus, $W(Q) = B(Q) - nC(Q/n)$, then the first order conditions in the Cournot oligopoly would be equivalent to the central planner case where the planner would maximise

$$F(Q) = (n-1)\,W(Q) + \pi(Q)$$

where $\pi(Q) = p(Q)Q - nC(Q/n)$ is the industry-wide profit. The Cournot equilibrium thus maximises a weighted sum of welfare and profits.

Dixit [31] has studied the comparative static properties of the Cournot oligopoly. He showed that the case of a positive cost shock or demand shift for firm i both the output and profit of firm i will increase, total industry output, Q, will increase and outputs and profits of all other firms will decrease. If a firm enters a new market, say abroad, sales in the foreign market would lower the firm's marginal costs in the home market, given that marginal costs fall with output. So the comparative static analysis of the Cournot equilibrium can be used for explaining incentives to enter a foreign market.

2.2.3 Numerical solution to the Cournot model

The Cournot equilibrium corresponds to the behavioural assumption that firms take other firms' possible reactions to their output decision as given. Here the equilibrium was solved numerically by fixing the conjectural derivatives to equal zero. The Cournot equilibrium solution with the nine largest Finnish electricity companies is presented together with the initial year values of some representative variables.

Table 2.2. Cournot equilibrium solution

	Initial	Cournot
Price elasticity of demand	0.60	0.60
Price of electricity (FIM/MWh)	160	219.60
Domestic generation (TWh)	62.25	45.69
Imports (TWh)	0.00	0.004
Consumer Surplus (bn. FIM)	0.00	-2.49

The equilibrium price rose from the base year level of FIM 160 per MWh to FIM 219.604 per MWh in the Cournot equilibrium with elasticity value 0.6. When the elasticity was assumed to be 0.9, the equilibrium price was FIM 165.3 per MWh, which is fairly close to the initial price level. The assumed 'base-case' elasticity value of 0.5 can be criticised for being too high. Andersson et. al [6], for example, used an elasticity value of 0.3. Here the reason is a practical one; when the elasticity value is smaller than the market share of the firms under study, the solution becomes infeasible (first order condition for profit maximisation was $\frac{P(Q)-c_i}{P(Q)} = \frac{s_i}{\varepsilon}$).

The largest company IVO reduced its coal based condensing power (by 5.7 TWh) and nuclear generation (by 1.9 TWh). PVO reduced its condensing power (by 4.4. TWh) and increased its nuclear generation[25] (by 5.7 TWh). The third largest company, Helsinki Energy, increased its condensing generation (by 1.6). The net effect was that total output was reduced and price rose. One can think of the new

[25] It was assumed that in the calibration simulation there was this amount of free nuclear capacity available to TSM. TSM/PVO owns over 50% of the Olkiluoto nuclear plants.

equilibrium in this model in terms of price responsive demand adjusting to the higher price level.

In the case of more elastic demand (0.9) it turned out that the largest firm could not affect the price level as much. As IVO restricted its supply (by about 7.5 TWh), this was largely compensated by increases in outputs of the other two large players, PVO and Helsinki Energy. As a result the market price remained close to the base year level.

2.2.4 Competitive equilibrium (Bertrand equilibrium)

While the assumption of perfect competition is easy to criticise, especially when applied to energy markets, the model remains useful for two reasons. One is practical; it is the simplest model to formulate and implement and is the easiest way to help to structure data collection for a market analysis. The second reason is that perfect competition provides a useful benchmark for analysing the degree of market imperfection in a market.

The perfectly competitive equilibrium is also the same as the Bertrand equilibrium, i.e. the case where firms compete on the price of a homogeneous good, and there is no capacity constraint with respect to the demand. A common objection to the Cournot model is that in reality it is prices that are the strategic variables for firms, not quantities. The first critique of the Cournot model along these lines was put forward by Bertrand [15], who argued that duopolists engaging in price competition will under-cut each other's price in order to capture the entire market. In the case of equally efficient firms, homogenous product and constant marginal costs the Bertrand-Nash equilibrium is the only one where each firm sets prices to equal marginal cost. In the case of many firms and non-symmetric cost structure (with constant costs) the firm with the lowest marginal cost will capture the entire market. This firm will equate the price with the second lowest marginal cost in the market. In contrast to the symmetric cost case the Bertrand equilibrium is not the first-best allocation, as the prices faced by customers exceed the marginal cost.

The Bertrand equilibrium with homogenous good and non-constant marginal costs may not exist. Adding fixed costs, for example, to the basic Bertrand model causes nonexistence of the equilibrium. Edgeworth [33] argued that the nonexistence of the Bertrand equilibrium also occurs with decreasing returns to scale. Kreps and Scheinkman [75] considered Edgeworth's case of constant marginal costs with capacity limits and showed that the nature of the equilibrium depends upon the firms' capacities in relation to demand. If capacities are large, the original Bertrand equilibrium will result. If capacities limit production, then each firm will choose a price consistent with their capacity. Kreps and Scheinkman showed that the two-stage Cournot equilibrium will result in capacity competition followed by price competition. This is feasible as capital is a sluggish variable, whereas prices can be adjusted rapidly.

2.2.5 Numerical solution to the competitive equilibrium

Table 2.3. reports results of the competitive equilibrium solution for Finland. The equilibrium is characterised by marginal cost pricing,

i.e. firms produce at the generation level at which the marginal cost (of the last plant taken into operation) equals the market price. The cases below were solved assuming a price elasticity value of 0.6. With a higher elasticity value (0.9) the price turned out to be lower than expected. In imperfectly competitive markets price elasticity affects the firms pricing via the mark-up equations, and a higher price elasticity leads, ceteris paribus, to a lower equilibrium price. Törmä [111] provided an econometric estimate of Finnish electricity demand elasticity which ranged between -0.15 and -0.6 depending on the industrial sector.

Table 2.3. Cournot equilibrium solution

	Initial	Competitive equilibrium
Price elasticity of demand	0.60	0.60
Price of electricity (FIM/MWh)	160.00	98.20
Domestic generation (TWh)	62.25	79.35
Imports (TWh)	0.00	0.00
Consumer Surplus (bn. FIM)	0.00	5.43

Compared to the initial year's level the total electricity generation in the competitive case increased by 19 TWh per year. This reflects the higher degree of competition and marginal cost pricing. The adjustment process cannot be analysed with the static model, which gives information only on equilibrium states of the market.

The competitive equilibrium improves consumers' welfare, measured by consumer surplus. With a price elasticity value of 0.5 the welfare improvement is roughly equivalent to 5 bn. Finnish marks -

not an insignificant effect.

2.2.6 Supply function oligopoly

In reality, firms choose both quantities and prices, but if they do so simultaneously, the problem of inconsistency may arise in a one-period model. Aggregate demand may not equal to aggregate supply. One way to reconcile the inconsistency problem is to think of firms choosing a vector of quantities and prices, a supply function, instead of points in a price-quantity space. Given each firms' supply functions the equilibrium is determined by the equality of the aggregate supply and demand. Supply function equilibria have been studied in detail by Klemeperer and Myer [72].

As an example, assume a linear demand curve

$$Q = a - bp \tag{19}$$

faced by two firms. For simplicity costs are assumed to be zero. Firm $i's$ strategy consists of choosing supply function

$$s_i = (0, \infty) \rightarrow (-\infty, \infty) \tag{20}$$

The market price $\overline{p}$ will be determined by

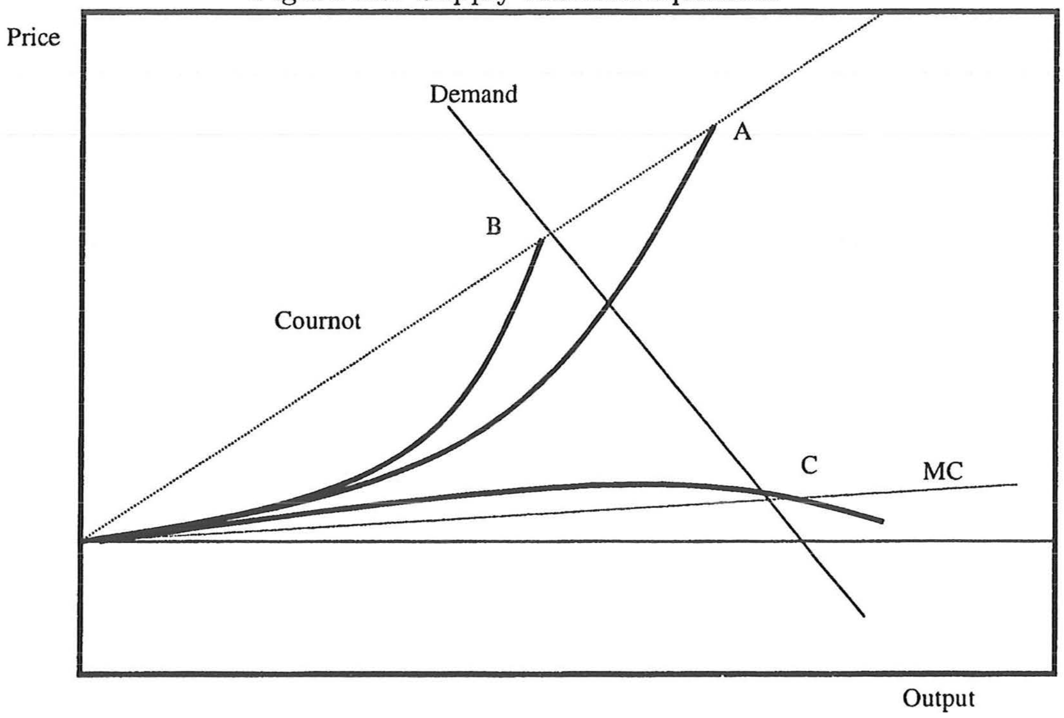
$$a - b\overline{p} = s_1(\overline{p}) + s_2(\overline{p}) \tag{21}$$

A pair of supply functions (s_1, s_2) is a supply function equilibrium (SF-equilibrium) if (s_1, s_2) is a Nash equilibrium. It can be shown that any point on the demand curve can be supported as an SF equilibrium.

Klemeperer and Myer [72] showed that once uncertainty is introduced the multiplicity of the SF-equilibria reduces rapidly and in some cases there is an unique equilibrium.

The SF-equilibrium is displayed graphically below in Figure 2.3.

Figure 2.3. Supply-function equilibria



The trajectories are solutions to a first order differential equation that represents the profit maximisation condition, $\frac{dq}{dp} = \frac{q}{p-C'(q)} + D_p$. The upper stationary corresponds to the Cournot supply schedule, while the lower stationary is reached at horizontal slope so that $\frac{dq}{dp} = 0$ and $p = C'(q)$,which is the competitive case. In general, any equilibrium between these is feasible. If the demand schedule can be arbitrarily high then a unique solution exists, see Klemeperer and Myer [72].

This model was not solved numerically, due to the different data requirement, but the equilibria would remain between the above two cases: the Cournot and the competitive equilibria.

2.2.7 Dominant Firms and a competitive fringe

Stigler [107] was first to develop a model for an industry with one dominant firm and a price taking competitive fringe. Dixit and Stern [32] emphasise that this model has many real world examples, such as the petroleum market where major companies attempt to exercise leadership and the dependants follow. This model has also been used for electricity spot-markets. The dominant-firm model differs from the Stackelberg's leader-follower equilibrium, however, in that Stackelberg model has one of the Cournot players acting as a leader and no competitive fringe. The dominant-firm model is in fact a combination of the Stackelberg model and the competitive model.

Let the supply curve of the competitive fringe be

$$s = s(p) \tag{22}$$

and assume that the fringe consists of n identical firms. When the dominant firm decides to choose price p and sell amount x the fringe reacts by supplying $s(p)$ so that total supply will equal $x+s(p)$. From the dominant firm's point of view the only feasible plan (p, x) is such that $x + s(p) \leq x(p)$, where $x(p)$ is the total demand in the market. If $y+s(p) > x(p)$ the price would fall and hence (p, x) would not be a feasible plan. The dominant firm then faces a residual demand curve

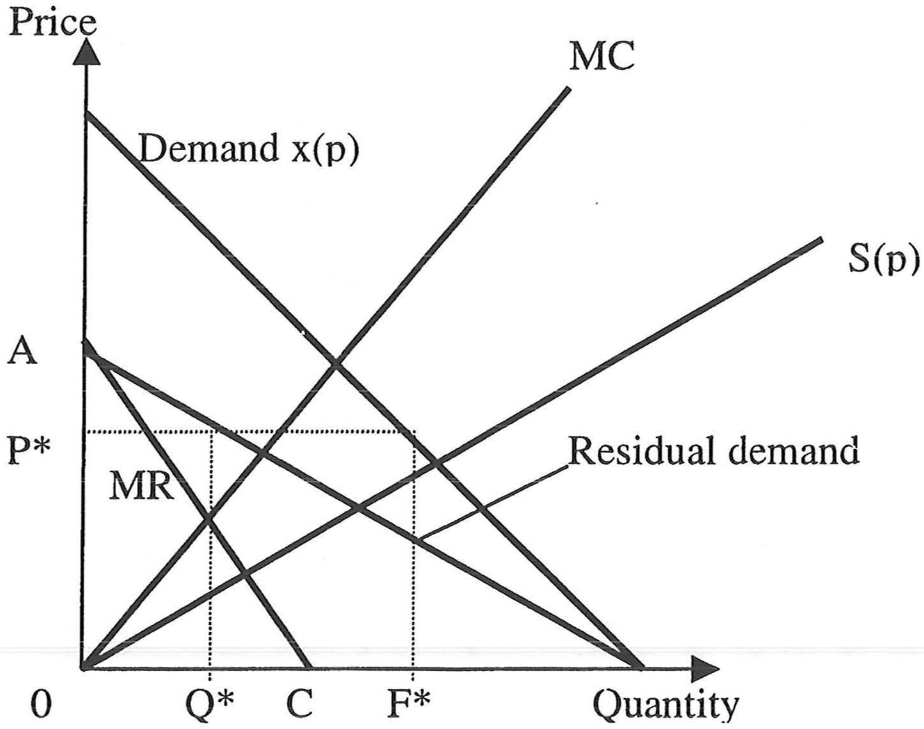
$$x = x(p) - s(p) \tag{23}$$

and its profits are given by

$$\Pi(p) = p \times [x(p) - s(p)] - c \times [x(p) - s(p)] \quad (24)$$

Below Figure 2.5 displays the equilibrium in this market. The residual demand is obtained by subtracting $s(p)$ from the aggregate demand $x(p)$. Let the dominant firm treat this as the demand curve confronting it and select a profit-maximising price. If MC is the dominant firm's marginal cost then P^* is such a price.

Figure 2.4 Cournot competition with competitive fringe



The dominant firm supplies $0Q^*$ and the competitive fringe produces Q^*F^*.

There can also be a market with many dominant firms and a competitive fringe. In the case of m dominant firms the price that will prevail is defined implicitly by

$$x_1 + .. + x_m + s(p) = x(p)$$

or $x_1 + .. + x_m = x(p) - s(p)$.

2.2.7.1 Numerical solution of the Cournot equilibrium with competitive fringe

In this case the smallest firms were bundled together to form a price-taking fringe. The largest firms set the market price and face residual demand (the market demand minus the competitive fringe supply).

Table 2.4. Cournot model with competitive fringe

	Initial	Competitive fringe
Price elasticity of demand	0.60	0.60
Price of electricity (FIM/MWh)	160.00	172.20
Domestic generation (TWh)	62.25	59.93
Imports (TWh)	0.00	0.00
Consumer Surplus (bn. FIM)	0.00	-0.72

The Cournot fringe equilibrium price rose less (to FIM 172.2 per MWh) when compared to the case with Cournot actors and no fringe, which gave the equilibrium price of FIM 219.60 per MWh. The fringe thus exerted a significant effect on the equilibrium price. Inspite of the 'competitive effect' from the existence of the fringe, the equilibrium price rose compared to the initial price level. From this point of view the Finnish market in isolation seems not be sufficiently competitive to guarantee more efficient pricing of electricity.

2.2.8 Conclusions

This chapter presented different oligopoly models and different solution approaches that have been applied to electricity spot market modelling. Market equilibrium solutions with 1994 database indicated that the Finnish electricity market structure, as an isolated system, would not necessarily yield more efficient market solution via free competition. One should bear in mind, however, that the Cournot model used represented the most extreme assumption of market power potential (in the set of different supply function equilibria) On the other hand, the existence of large bilateral contract market (which was not explicitly considered) along side with the electricity exchange spot market is bound to alleviate the market power potential via facilitating more credible entry threat of new generators to the market, see Newbery [88] .

In the Cournot equilibrium the market equilibrium price rose from FIM 160 per MWh in the base year to FIM 219.604 per MWh in the Cournot equilibrium, assuming an price elasticity value 0.6. When the elasticity was assumed to be 0.9, the equilibrium Cournot price was FIM 165.3 per MWh, which is fairly close to the initial price level. The Cournot equilibrium included only the nine largest generators in the market. When the rest of the generators were included as one competitive fringe firm the resulting Cournot fringe equilibrium price rose slightly less (to FIM 172.2 per MWh) than in the Cournot case without the competitive fringe. Whether the fringe affects the market price depends on its relative size.

In the case of perfectly competitive market equilibrium the market price turned out to be FIM 98.2 per MWh. Compared to the initial year's level the total electricity generation in the competitive case increased by 19 TWh per year. This reflects the higher load level resulting from lower price level. The competitive equilibrium improves consumers' welfare, measured by consumer surplus. With price elasticity value of 0.5 the welfare improvement is roughly equivalent to 5 bn. Finnish marks.

Finland cannot be treated, however, as an isolated system. The Nordic electricity markets have long tradition of co-ordination and co-operation and since the deregulation electricity trading has been integrated. Also, restrictions to trade across national borders have been lifted and at the same time the largest companies (Fortum and Vattenfall most notably) have acquired considerable shares of their Nordic rivals. The next section extends the analysis to the Nordic electricity markets.

3 Competition in the Nordic electricity markets

In this chapter the market-based model used above is extended to a three country two-price region setting. The three countries are Norway, Finland and Sweden which make up two price regions: the combined Norwegian-Swedish market and the Finnish market. The division into two price areas is motivated by the fact that Norway and Sweden were running a joint market place, the Nordpool, while electricity flows from Finland to the Nordpool was subjected to a tariff. The two markets are interconnected with a given transmission capacity. Subsequently the three countries are 'integrated' in that there is no border costs. If the transmission capacity is sufficient then of course a single price will result in the both areas.

A numerical/analytical model is first presented, after which the numerical results for different market equilibria are presented.

3.1 An electricity market model for the Nordic market

This chapter extends the above single region model into two region model that represents two price regions: the unified Norwegian-Swedish market on the one hand and the Finnish market on the other. Again the largest generators from all three countries were chosen as potential price setting firms. The two price regions are connected with a single transmission line with a given capacity.

Firm behaviour is again based on the Cournot assumption that generators compete on quantities and do not take into account others' possible retaliation. Each firm optimises the utilisation of its mix of generation plants. This follows from minimising the total cost of generation subject to plant capacities and for a given total output. The plant optimisation problem is given as

$$\begin{aligned} &\min_{X_{fi}} \sum_i C_{fi} X_{fi} \\ &s.t. \\ &X_{fi} \leq \bar{K}_{fi}\ ; \qquad \lambda_{fi} \\ &X_f \leq \textstyle\sum_i X_{fi}\ ;\ \mu_f \end{aligned} \tag{25}$$

The marginal cost of plant i belonging to firm f is specified as the sum of firm-independent generation cost[26] , c_i , and the shadow price

[26] The following estimates were used (FIM/MWh): Hydro (10), CHP (50), NUC (40), Condensing (90) & PEAK (150)

of capital, λ_{fi} , so that $C_{fi} = c_i + \lambda_{fi}$.

The first order conditions are given as

$$\begin{aligned} \mu_{\mathrm{f}} - c_i - \lambda_{fi} &\leq 0 \\ X_{fi}\,(\,\mu_{\mathrm{f}} - c_i - \lambda_{fi}) &= 0 \\ X_{fi} - K_{fi} &\leq 0 \\ \lambda_{fi}\,(X_{fi} - K_{fi}) &= 0 \end{aligned} \tag{26}$$

The Lagrange multipliers associated with the constraints can be interpreted as the shadow price of an extra unit of capacity (λ_{fi}) and the marginal cost of firm f (μ_f).

For an analysis of profit maximisation and market equilibria we use a simplified model setting that allows for an analytical solution. Assume that in each of the two regions, say F and N, there is one firm producing a single homogeneous good E. The two regions are segmented by the existence of a transport cost τ. In addition, the total net exports from either region are constrained by a transmission line with an exogenous capacity, $\overline{EXP}$. If the line becomes congested there is an associated shadow value of the capacity which is interpreted as an additional cost of export, ω. In reality, bottlenecks are dealt within the price mechanism so that the price is reduced in surplus areas and increased in deficit areas until the transmission need has been reduced to the capacity level. The participants are charged the costs through the so-called capacity fee (in the surplus area the capacity fee is debited to the seller and credited to the purchaser, and vice versa in the deficit area).

The constraint for the transmission capacity between the two price areas is given by

$$|E_F - E_N| \leq \overline{EXP} \tag{27}$$

The profits of a firm in the two regions become

$$\Pi_F = X_F \times P_F + E_F \times P_N - C_F \times [X_F + E_F \times (\tau + \omega_F)] \tag{28}$$

$$\Pi_N = X_N \times P_N + E_N \times P_F - C_N \times [X_N + E_N \times (\tau + \omega_N)] \tag{29}$$

where X_F is the output supplied to the domestic market by the firm in region F and E_F is exports to region N. P_F is the inverse demand in region F. Parameter τ (> 1) denotes the transport cost between the two regions. The inverse demand functions are of the constant price elasticity form

$$P_F = A_0 (Y_F)^{1/\varepsilon} \tag{30}$$

$$P_N = B_0 (Y_N)^{1/\varepsilon} \tag{31}$$

where $Y_F = X_F + E_N$ and $Y_N = X_N + E_F$ are the total supplies in the two regions. Marginal costs were assumed to be constant, which allowed us to focus on one market alone, here market F. Assuming

Cournot behaviour the first order conditions of the profit maximisation for output supply to market F are given by

$$\frac{\partial \pi_F}{\partial X_F} = P_F + X_F P_F' - C_F \qquad \leq 0 \tag{32}$$

$$\frac{\partial \pi_N}{\partial E_N} = P_F + E_N P_F' - \frac{C_N\left(1+\omega_N\right)}{\tau} \leq 0 \tag{33}$$

With X_F and E_F positive (6) and (7) can be rewritten as

$$P_F = \frac{\varepsilon C_F}{\varepsilon + SN - 1} \tag{34}$$

$$P_F = \frac{\varepsilon C_N\left(1+\omega_N\right)}{\tau\left(\varepsilon - SN\right)} \tag{35}$$

where $\varepsilon = \frac{-P_F}{(X_F+E_N)\times P_F'}$ is the price elasticity of the demand in market F and $SN \equiv \frac{E_N}{(X_F+E_N)}$ is the foreign firm's market share in market F.

Brander and Krugman [22] showed that in a case of symmetric firms a sufficient condition for intra-industry trade is $\varepsilon < \frac{1}{1-\tau}$, where τ is the transport cost. When costs differ, say $C_F > C_N$, the condition becomes $\varepsilon < \frac{C_N}{C_N - \tau \times C_F}$.

3.1.1 The effect of arbitrage

There was no explicit consideration of the effects of the potential resale of electricity back to its source market. The crucial factor in modelling arbitrage is how it is incorporated into firms' profit-maximising behaviour. If it is treated as a market constraint and not included explicitly in the firms' marginal revenues the effect on the trade pattern will remain small compared to the case when arbitrage is incorporated into the firm's profit maximisation (see Wong (1995) p. 319). It is, however, difficult to justify the latter case under the Cournot assumption in which firms take other firms' output as given. Therefore we only consider the case in which the arbitrage condition is taken as a 'market constraint'.

It is assumed that there are many competitive trading companies in both countries that are able to purchase electricity from a market when the price is sufficiently low, and to sell it to the other market. Let the amount of electricity resold from N to F be denoted by θ. Market clearing conditions in the two markets become

$$D_F = X_F + E_N + \theta \tag{36}$$

$$D_N = X_N + E_F - \theta \tag{37}$$

where D_F, D_N denote the total demands. $\theta \geq 0$ whenever $P_F(Y_F) \geq P_N(Y_N) + \tau$. If, however the transmission line becomes congested no arbitrage can of course occur. This was taken into account by including the shadow price ω the arbitrage condition:

$$P_F(Y_F) \geq P_N(Y_N) + \tau + \omega \tag{38}$$

This eliminates a situation where both $\theta > 0$ and $\omega > 0$. In fact, whenever $\omega > 0$ then $\theta = 0$.

3.2 Model solution & calibration

The model was solved using the GAMS/MCP package with the MILES solver. A Mixed Complementary Problem (MCP) format was used [27], see Rutherford [98], for the equilibrium solutions. The MILES employs a modified Newton algorithm with a backtracking line search. The method is based on Mathiesen [82].

The model was calibrated for 1994 data by fixing the reference year domestic output and export levels at their actual levels and allowing conjectural elasticity variables to be freely determined. These are specified in first order conditions of the profit maximisation, which for a firm with market share s_i facing demand with elasticity of ε can be written as

$$\frac{P(Q) - c_i}{P(Q)} = \frac{\alpha_i + (1 - \alpha_i) s_i}{\varepsilon} \tag{39}$$

where $\alpha_i = \frac{d\log(q_j)}{d\log(q_i)} = \frac{q_i}{q_j}\frac{dq_j}{dq_i}$ is the conjectural elasticity. The elasticity α_i denotes how much firm i perceives firm j changes[28] its output when i changes it by 1%. The solved values of the conjectural elasticities displayed the general tendency that the larger the company the smaller the value.

[27] As in the case of the Finnish market, i.e. in general form: find $z \in R^n$ *so that* $F(z) \geq 0, z \geq 0$ *and* $z^T F(z) = 0$

[28] Dixit (1986a) warns, however, that taking account of others' reactions fit poorly with one-shot games

Table 3.1 Reference year values for some aggregated variables

Supply in Finland (TWh)	51.9
Supply in Nordpool (TWh)	206.98
Price in Finland (FIM/MWh)	160
Price in Nordpool (FIM/MWh)	130
Exports from Finland	0.589
Exports from Nordpool	1.66

An elasticity value of -0.6 was assumed in both markets. Törmä [111] has estimated the electricity demand price elasticity to range between -0.15 and -0.8, depending on the industrial sector.

3.3 Market equilibria scenarios

3.3.1 A normal water year scenario

'Normal year' here refers to the assumed level of Norwegian-Swedish hydro capacity. Norway's Ministry of Industry and Energy estimates the maximum installed capacity of hydro generation for the ten largest companies to be about 18000 MW (or about 160 TWh per year). For the normal year simulation we assumed that average hydro capacity corresponded to 109 TWh p.a. For Swedish firms the maximum installed hydro capacity was 15515 MW, according to the Swedish Power Association. A similar ratio (about 70 % of the theoretical maximum) to the Norwegian case was used to estimate the average hydro capacity level.

Both the Cournot-Nash equilibrium and the perfectly competitive equilibrium solutions are reported. The perfect competition equilibrium is a useful benchmark to compare to other market structures, but as Smeers [103] notes, it is also important as a benchmark against which market imperfections may be assessed. Hjalmarrson [60] found that the Nordic electricity spot-market equilibrium was in fact close to the competitive one.

Compared to the reference year the Cournot equilibrium was characterised by a fall in both price levels; in Finland the price was FIM 110.9 per MWh and in Nordpool FIM 79.9 per MWh. Total exports from Finland amounted to 5.4 TWh and total exports from Nordpool 20.4 TWh. The transmission line became congested at the assumed capacity of 15 TWh. The shadow value of transmission capacity was FIM 20.7 per MWh.

The perfectly competitive equilibrium price fell further to FIM 90 per MWh in Finland and FIM 68.7 per MWh in Nordpool. This price differential exactly mirrors the border tariff (FIM 17 per MWh) plus the shadow price of the congested capacity (FIM 4.3 per MWh). In the competitive equilibrium, total exports from Nordpool were at the assumed maximum of 15 TWh.

Table 3.2. Cournot-Nash and competitive solution for a normal year

Normal Year	Reference	Cournot	Competitive
Price FIN	160.00	110.90	90.00
Price Nordpool	130.00	76.90	68.70
Transmission capacity value	0.00	23.10	2.30
Exports from Finland	0.59	4.50	0.00
Exports from Nordpool	1.60	19.50	15.00

3.3.2 Integrated market scenario and effect of arbitrage

The above section shows that in an average year the transmission line becomes congested because of power flow from the low-cost market to the high-cost one. When the transmission capacity is raised sufficiently and the border tariff abolished the two regions become an integrated market. In this case the Cournot equilibrium price in Finland was FIM 78.7 per MWh and in Nordpool FIM 78.9 per MWh. Total net exports to Finland were 32.1 TWh. The competitive equilibrium price was FIM 76.3 per MWh with 33.6 TWh net exports to Finland.

Table 3.3. Cournot-Nash and competitive solution for an integrated market

Normal Year	Reference	Cournot	Competitive
Price FIN	160.00	78.70	90.00
Price Nordpool	130.00	78.90	68.70
Transmission capacity value	0.00	0.00	0.00
Exports from Finland	0.59	35.50	0.00
Exports from Nordpool	1.60	67.60	33.60

With the possibility of resale of electricity the Cournot-Nash equilibrium price was FIM 78.8 per MWh. A 2.1 TWh resale of electricity from Finland back to Nordpool took place. As Table 3.3 indicates, the Cournot price in Nordpool was slightly higher than the Finnish price level. Overall, inclusion of the arbitrage condition had little effect on the Cournot equilibrium.

Table 3.4. *Arbitrage in the integrated market*

Normal Year	Reference	Cournot	Competitive
Price FIN	160.00	78.70	76.30
Price Nordpool	130.00	78.90	76.30
Transmission capacity value	0.00	0.00	0.00
Exports from Finland	0.59	35.50	0.00
Exports from Nordpool	1.60	67.60	33.60

3.3.3 A dry year scenario

A dry year scenario was simulated by assuming Norway's and Sweden's maximum hydro generation capacity to be the same as their actual hydro generation in 1994. The dry year scenario produced a considerable price rise, to FIM 123.0 per MWh in the Cournot-Nash equilibrium. In Finland the price was FIM 133.35 per MWh. The near-equalisation of generation costs between the two regions also had the effect of inducing a high level of two-way trade. This can be interpreted as 'reciprocal dumping' (Brander and Krugman [22]) a phenomenon from the trade literature that takes place in symmetric markets with imperfect competition. Brander and Krugman [22] showed in a simple model that two-way trade can occur with an identical product when some barrier (for example border tariff) exists between the countries. Profit maximisation implies that these firms sell positive amounts of their products to both 'segmented' markets under certain mild conditions. This is because the perceived marginal revenue is higher in the export market, which follows from the firms' smaller market share of their export markets.

The competitive equilibrium in the dry year is characterised by total exports of only 0.05 TWh from Finland, indicating equality in the cost structures between the regions.

Table 3.5 Cournot-Nash Competitive solution for a dry year

Normal Year	Reference	Cournot	Competitive
Price FIN	160.00	133.35	108.50
Price Nordpool	130.00	123.00	125.50
Transmission capacity value	0.00	0.00	0.00
Exports from Finland	0.59	35.50	0.05
Exports from Nordpool	1.60	67.60	00.00

3.3.4 Cournot equilibrium with competitive fringe

It may be argued that it is only the few largest electricity companies that act in a non-price-taking manner, while the rest take the market price as given. In Finland, for example, IVO can be considered as having market power, in Sweden the largest firms Vattenfall and Sydkraft, and in Norway Statkraft. Equilibrium prices and quantities were solved for a case where these largest Nordic electricity companies were acting as Cournot firms while all the rest were assumed to be price takers and aggregated as two competitive 'fringes' (The dominant firms were assumed to follow the Cournot strategy).

In this model the dominant firms decide on quantities, taking into account that the competitive fringe responds to the resulting market price with total competitive supply, $s(p)$[29]. The feasible strategy of

[29] Which is of course a sum of the marginal costs of the competitive firms in the fringe.

the dominant firms is to choose output level that does not cause the market price to fall. If the total output by the dominant firms plus the fringe output is higher than the total market demand the price will clearly fall. Hence, from the dominant firms' point of view a quantity strategy is feasible only if the sum of the total supply of the dominant firms and the competitive fringe supply is less than the total demand.

The dominant firms face a residual inverse demand which is given by the total market demand with the fringe supply subtracted, i.e. $P = P\left(\sum X_f - s(p)\right)$.

The results of this equilibrium are reported in table 3.6.

Table 3.6. Cournot-Nash and competitive solution for a competitive fringe

Normal Year	Reference	Cournot	Competitive
Price FIN	160.00	95.30	90.00
Price Nordpool	130.00	81.20	73.00
Transmission capacity value	0.00	7.40	0.00
Exports from Finland	0.59	7.40	0.00
Exports from Nordpool	1.60	22.40	11.90

Compared to the normal year simulation the Cournot fringe equilibrium had a higher Nordpool price (FIM 95.5 per MWh vs. FIM 76.9 per MWh in the normal year), but the Finnish prices were identical in the two solutions. This reflects the fact that the Finnish market is more concentrated than Nordpool and hence the relative size of the fringe is larger in the latter.

3.3.5 Elastic demand

A final 'policy simulation' involved increasing the elasticity of the demand from the above -0.6 to -1.1 in both regions. As the elasticity of demand increases the Cournot equilibrium should approach a competitive solution. The competitive equilibrium prices were FIM 107 per MWh in Finland and FIM 90 per MWh in Nordpool. The transmission line was not congested with total one-way exports of 10.3 TWh from Nordpool.

The Cournot equilibrium prices were FIM 120 per MWh in Finland and FIM 91.8 per MWh in Nordpool. The price differential was exactly the shadow value of the line capacity plus the border tariff, as in the competitive equilibrium.

Table 3.7.. Cournot-Nash and competitive solution for a elastic demand

Elastic demand	Cournot	Competitive
Price FIN	120.00	107.00
Price Nordpool	91.80	90.00
Line Capacity	21.20	0.00
Exports FIN	0.00	0.00
Exports Nordpool	15.00	10.30

3.4 Conclusions

This chapter has considered several possible market equilibria in competitive electricity market that represented a three country Nordic electricity market by a two-region oligopoly model. Both the Cournot-Nash and competitive equilibrium solutions were solved and reported in all different market scenarios that were simulated. The model was calibrated to the 1994 data assuming an equilibrium price of FIM 160 per MWh in Finland and FIM 130 per MWh[30] in Nordpool. In 1994 total exports were 0.59 TWh from Finland to Nordpool and 1.6 TWh from Nordpool to Finland. Total transmission capacity between the regions was assumed to allow a total of 15 TWh of net exports yearly. A cross-border tariff of 17 FIM per MWh was assumed to prevail initially.

The results indicated that a competitive Nordic electricity market improves pricing efficiency. In the case of normal year scenario with two price regions the Cournot equilibrium prices fell in both Finland and in the Norwegian-Swedish region (Nordpool) compared to the 1994 levels. The assumed transmission net capacity of 15 TWh per year between Finland and Nordpool became congested in the normal year scenario. In reality some of this capacity is reserved by electricity companies for their use only, increasing the potential for transmission bottlenecks.

The normal year simulation was implemented by presenting the average annual hydro capacity as about 70% of the theoretical maximum of hydro generation in Norway and Sweden. Compared to the reference year price level the Cournot-Nash equilibrium price fell from FIM 160 to FIM 110.9 per MWh in Finland, while the Nordpool price fell from FIM 130 to FIM 79.9 per MWh. The transmission line became congested. The competitive equilibrium price level was FIM 90 per MWh in Finland and FIM 68.7 per MWh in Nordpool. This price difference exactly equalled the border tariff (FIM 17 per MWh) plus the line capacity value (FIM 4.3 per MWh). In a competitive equi-

[30] All prices are quoted in FIM/MWh. 1 FIM=0.7 SEK.

librium the trade pattern is always one-way from the low cost region (Nordpool) to the higher cost one (Finland).

When the border tariff was abolished and the transmission capacity constraint lifted the two price regions became one integrated market. In the Cournot equilibrium prices were almost equalised to FIM 78.7 per MWh in Finland and FIM 78.9 per MWh in Nordpool; the reason they were not identical was that the Cournot model does not take into account possibility of arbitrage in the form of re-selling electricity from one market to another, which would equalise them. When the effect of arbitrage was taken into account the unified price turned out to be FIM 78.8 per MWh. The competitive equilibrium price in the integrated market was FIM 76.3 per MWh in both regions.

In the dry year simulation, Norway's and Sweden's maximum hydro generation capacity was assumed to be the same as their actual hydro generation in 1994. As a result the marginal costs of electricity generation in Nordpool rose close to the Finnish level. The Cournot equilibrium was characterised by a high degree of two-way trade (reciprocal dumping a la Brander and Krugman 1983). In the competitive equilibrium trade between the regions almost disappeared, with Finland exporting a mere 0.05 TWh to Nordpool.

Other simulations included a dominant-firm vs. competitive fringe market and an elastic demand simulation. In the competitive fringe Cournot equilibrium the Nordpool price level was higher than in the normal year simulation while the Finnish price level remained the same. This reflects the fact that Nordpool is a less concentrated market and the residual demand over which the dominant firms compete is relatively smaller than in Finland. In the elastic demand case a price elasticity of -1.1 was assumed instead of the -0.6 assumed above. As one would expect the Cournot equilibrium moved towards a competitive outcome as the demand elasticity was increased.

4 Technical efficiency and productivity in the Finnish electricity generation 1994-1996

The previous chapters analysed the effects of market liberalisation in Finnish and Nordic electricity markets using models of competition that represent the equilibrium outcomes in these markets. The focus was on solving the market equilibrium and market prices with existing generation and transmission capacities. The results indicated that competition has indeed improved pricing efficiency, especially within the integrated Nordic electricity markets.

The main focus of the following chapters is on measuring the performance (efficiency and productivity) of the Finnish electricity market. Deregulation and privatisation are two policy issues where measurement of productive efficiency have been used extensively to quantify changes that are predicted qualitatively by theory.

Privatisation involves change in an industry's ownership structure. In the UK a privatisation program was part of the electricity market reform. Changing the ownership structure alongside the introduction of a competitive market environment was regarded as essential for boosting the companies' performance. Theoretical literature on ownership structure suggests that under public ownership managers' incentives to seek maximum efficiency is reduced, due to the fact that property rights cannot be transferred [31] (Alchian [3]). Moreover, it

[31] a tax-payer cannot sell her implicit share in a state-owned utility

has been argued that in public utilities bureaucrats maximise budgets rather than minimise costs (Niskanen [89]). Empirical evidence on the effect of the ownership structure on performance seems, however, to be mixed (see Pollit [94] for evidence on US/UK electricity industries.

Theoretical predictions of the effects of regulation have evolved over time. Traditional theory argued that regulation serves the public interest by correcting some market failure (forming a natural monopoly for example). The underlying assumption was that a perfectly informed welfare maximiser manages the regulation or runs the regulated firms efficiently. This assumption is clearly the weakness of the so-called public interest theory of regulation. Averech and Johnson [12] criticised the public interest theory by focusing on the regulated firm's behaviour, arguing that a cost-of-service regulation leads to over-capitalisation, as the firms have an incentive to expand their rate base. Although the empirical evidence for this over-capitalisation effect is mixed (Joskow and Noll[67]) other empirical work has challenged the public interest theory by finding that regulation either had no effect on the conduct of the firms (Stigler and Friedland [108]) or that the regulation in fact creates inefficiencies rather than eliminating them (Meyer et al.[84]).

Joskow and Noll[67] point out that according to the public interest theory of regulation the effect of deregulation is positive in terms of efficiency improvements if the costs of regulation exceed the transaction costs of abolishing it plus the costs of any market failure. According to the so-called Chicago Theory of Regulation, due to Pelzman [92], deregulation will increase welfare as broad, diffuse groups (usually customers) benefit more than well-organised, compact groups (frequently firms).

Two possible ways in which productive efficiency can improve with deregulation are: firstly, as inefficient operations in the insulated market regime are curtailed, and secondly, as rents that accrue to well-organised groups are dissipated by the introduction of competition.

Performance analysis of the regulated electricity distribution sector is also important as the competitive generation and sales markets have raised the question of improving efficiency in the natural monopoly sectors of an ESI as well. Regulatory schemes are being developed to achieve efficiency improvements in the network sectors. In Norway, for example, the regulator calculates company-specific cost-efficiencies as part of the regulation (see Appendix 1).

In the following two chapters the performance of two Finnish electricity sectors is measured: competitive generation and regulated distribution (Chapter 5).

4.1 Technical efficiency and productivity - definitions

This section presents the formal definition of efficiency and productivity concepts that are utilised later on. The seminal work is due to Farrell [39] who constructed the reference best practice frontier of production with a linear approximation consisting of convex combinations of input-output levels of a subset of the firms in the industry. A firm was defined as *technically efficient* if no other firm, or convex combination of firms, lay on a ray between it and the origin. Charnes, Cooper and Rhodes [27] (CCR) calculated the Farrell measure of technical efficiency using a linear programming method which constructs a piecewise linear efficient production frontier from the observed data points. The method is called Data Envelopment Analysis (DEA). Forsund et al. [41] and Lovell and Schmidt [79] have listed three other methods of modelling the efficient production frontier: parametric programming (PPA), deterministic statistical frontier (DFA) and stochastic frontier analysis (SFA).

In the parametric programming method, due to Aigner and Chu [2], the parametric functional form of the production frontier is specified. Then the sum of absolute residuals (efficient minus observed input/output levels) subject to their positivity constraint is minimised. Technical efficiency scores can be calculated from the residuals. This method requires only one LP solution rather than one for every firm, as in the DEA method.

The DSA method, first used by Afriat [1], uses statistical techniques to estimate the efficient frontier. A one-sided error term in output function represents technical inefficiency relative to a deterministic frontier. The SFM method of Aigner et al. [2] also allows the possibility of measurement error. Thus deviation from the frontier can be decomposed into technical efficiency and the estimate for the measurement error.

The DEA method is the most general one, in that no assumptions are required of the functional form of the efficient frontier. Below the DEA method is presented in more detail as this method is used in this study..

4.1.1 Technology, efficiency and productivity

The concept of efficiency in production can be formalised by using a production set notion of production. A production set is a collection of pairs of vectors (x, y) that are *feasible,* i.e. y can be physically produced by using x. An input set $L(y)$ is defined as

$$L(y) = \{x : (y, x) \ is \ feasible\} \tag{40}$$

where $x = (x_1, ..x_n) \in R^n_+$ is an input vector and $y = (y_1, ..y_m) \in R^m_+$ is an output vector. The set notion becomes handy since the boundary of the set conforms with efficient production, while the interior of the set denotes inefficient production plans. A boundary set, called the isoquant set, for every $y \in R^m_+$ is defined as

$$L^{ISOQ}(y) = \{x : x \in L(y),\ \lambda x \notin L(y);\ \lambda \in [0, 1)\} \tag{41}$$

Another, more stringent, boundary set called the *efficient set* is defined as

$$L^{EFF}(y) = \{x : x \in L(y),\ x' \notin L(y),\ x' \leq x\} \tag{42}$$

Clearly $L^{EFF}(y) \subseteq L^{ISOQ}(y)$. As a measure of distance from a boundary set Shephard [100] introduced an input distance function defined as

$$D_I(y, x) = \sup\left\{\lambda : \left(\frac{x}{\lambda}\right) \in L(y)\right\}; D_I(y, x) \geq 1 \tag{43}$$

The isoquant set can be defined with the distance function as

$$L^{ISOQ}(y) = \{x : D_I(y, x) = 1\} \tag{44}$$

The Farrell input-oriented[32] measure of technical efficiency is defined as a minimum (or more generally infimum) radial decrease of an input vector for a given y

$$F_I(y,x) = \inf\{\lambda : \lambda x \in L(y)\} \tag{45}$$

Clearly $F_I(y,x) \leq 1$ and for a technical efficient unit $F_I(y,x) = 1$. The distance function and the Farrell measure of technical efficiency are related reciprocally

$$F_I(y,x) = \frac{1}{D_I(y,x)} \tag{46}$$

In the well-known study by Charnes, Cooper and Rhodes [27] (CCR), the authors assumed constant returns to scale technology and formulated the search for Farrell technical efficiency as a linear program.

An *envelopment* form of the program is given by

$$\begin{aligned} &\min_{\theta,\lambda_i} \ \theta \\ \text{st.} \quad &\sum_{i=1}^{K} \lambda_i y_{im} \geqq y_m, \forall m \\ &\sum_{i=1}^{K} \lambda_i x_{in} \leqq \theta x_n, \forall n \\ &\lambda_i \geqq 0, \forall i \end{aligned} \tag{47}$$

where the non-negative weights (also called intensity variables), λ_i, determine the best practice technology frontier for unit i. The scalar θ

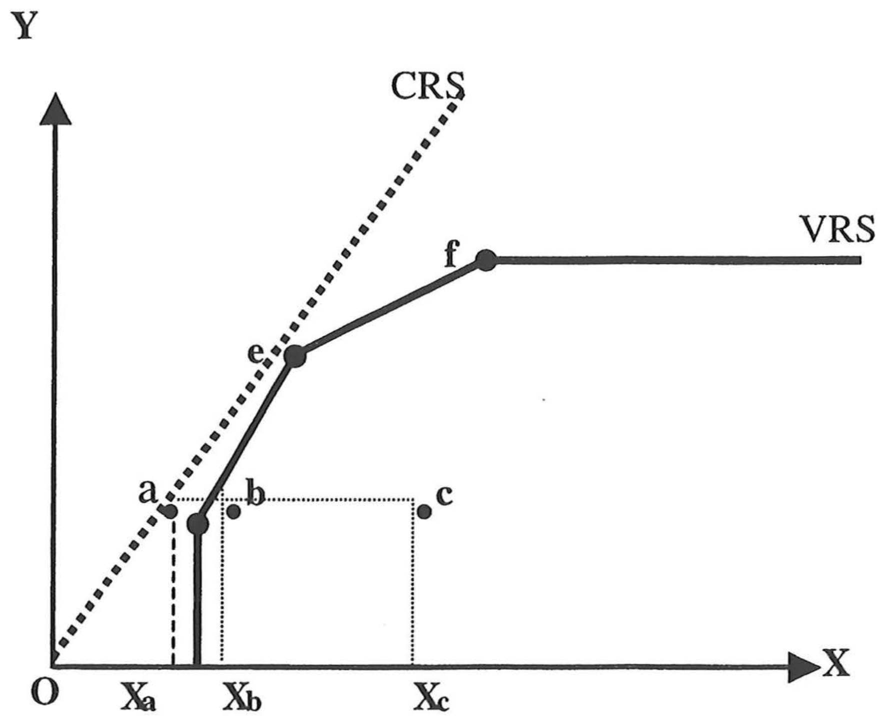
[32]Input-orientation refers to the property that the efficient frontier is reached by equiproportional change of all inputs with a given output. Output-orientation considers maximum output with given inputs

is the technical efficiency score and indicates the proportion by which all inputs must be decreased if they are to be utilised efficiently. The efficiency score $\theta = 1$ indicates technical efficiency and the score $\theta < 1$ technical inefficiency.

In the linear program above, constant returns to scale was imposed by assuming unrestricted intensity variables, i.e. $\lambda_i \geqq 0, \forall i$. Under variable returns to scale (VRS) the intensity variables would be constrained by condition $\sum_{i}^{K} \lambda_i = 1$, $\lambda_i \geqq 0; \forall i$, which implies that the efficient frontier would be convex combination of the efficient firms. In effect, the CRS model forms a conical hull of the feasible production set while the VRS model forms a convex hull of the set. Therefore the Farrell technical efficiency scores obtained with the VRS technology are always greater or equal to those with the CRS assumption.

Figure 4.1 illustrates the different cases in a simple one-input (X) one-output (Y) setting. The observed data points are labelled from **a** to **f**. Two production frontiers are shown: CRS and VRS. The CRS frontier is determined by the most productive unit, here the firm **e**, which is the only technically efficient unit. The input-oriented technical efficiency score under VRS technology for firm **c** is given by the ratio $\frac{0X_c}{0X_b} < 1$, and under CRS technology by $\frac{0X_c}{0Xa} < 1$.

Figure 4.1 Returns to Scale and Technical Efficiency



Scale efficiency is often measured as a ratio of two efficiency scores under the two scale assumptions

$$S_I(y, x) = F_I(y, x \mid CRS) \; / \; F_I(y, x \mid VRS) \qquad (48)$$

where $F_I(y, x \mid CRS)$ denotes the technical efficiency score under CRS and $F_I(y, x \mid VRS)$ is the technical efficiency score under VRS. A firm is said to be scale efficient if and only of $S_I(y, x) = 1$.

4.1.2 Plant capacity utilisation

An electricity generation plant may be idle for a considerable time if other, lower marginal cost capacity is available. In Finland, this is the case for large coal plants which may have a very low load factor if for example there is an abundance of cheap Swedish hydro generated electricity available. Johansen [65] defined plant capacity as the maximal amount that can be produced per unit of time with existing plant and equipment without restrictions on the availability of variable production factors, assuming normal conditions with respect to shifts, hours etc. Färe et. al. [45] related the Johansen definition in terms of the distance functions; they defined capacity utilisation as the ratio of two output oriented distance functions

$$CAPU\left(x^t, x_f^t, y^t\right) = \frac{D_o^t\left(x_f^t, y^t\right)}{D_o^t\left(x^t, y^t\right)} = \frac{TE_o\left(x^t, y^t\right)}{TE_o^f\left(x_f^t, y^t\right)} \tag{49}$$

where $D_o^t\left(x_f^t, y^t\right)$ is a distance function with only fixed factors included. In the denominator $D_o^t\left(x^t, y^t\right)$ is a distance function with all inputs included. TE_o is the Farrel output-oriented technical efficiency score. The Johansen definition is interpreted so that the existing plant and capacity refers to fixed inputs, while the remaining factors are considered as variable ones. The fixed factors form the plant capacity. In Johansen's definition the availability of the variable factors is not restricted. This is operationalised in the linear program above, which calculates the Farrel efficiency measures (reciprocals of the distance functions) by omitting the constraints on the intensity variables associated with the variable inputs.

The value of the ratio $CAPU\left(x^t, x_f^t, y^t\right)$ is equal to or less than one. This is because in the denominator, the value of the efficiency score is calculated with no restrictions on the variable inputs, and hence it will always be at least as large as the value in the nominator, where all inputs are included.

The above notion of capacity utilisation is more accurate than a traditional output to capacity ratio. The latter includes inefficiency in the output, and hence may downward bias the degree of capacity utilisation, which should be measured at the technically efficient output level.

4.1.3 Productivity

Productivity refers to the ratio of output to its inputs. With a single output and a single input there is no problem in measuring productivity. In practice, however, it is likely that a production unit produces many outputs with many inputs. With multiple-output and multiple-input technology one faces an aggregation problem. The earliest (and perhaps the simplest) measures of productivity were based upon ratios of the aggregate output to an input, typically labour. The productivity ratios were typically normalised to a certain year and used to assess total productivity development over time. The use of partial factor productivity analysis has the advantage of being simple and easy to compute (and understand). Partial measures fail, however, to account for interaction of different inputs - the substitution of capital for labour, for example, or the introduction of more efficient capital goods.

A more comprehensive measure of productivity, total factor productivity (TFP), takes into account all outputs and all inputs. With a single output and single input the productivity change is given as the ratio $\frac{y_{t+1}/x_{t+1}}{y_t/x_t}$. With many outputs and many inputs different weighting schemes become available. In discrete time applications two well-known examples of TFP measures are the Törnqvist and the Fisher productivity indexes, both of which utilise price and quantity data[33] for the TFP measure. In a continuous time setting the method of neoclassical growth accounting is another well-known approach to measuring total factor productivity. In this approach differentiating a transformation function, $F(k, l; t) = 0$, with respect to time t gives an expression, also known as a Divisia index, for the shift of the function. Change in the TFP is interpreted as technical change. Both the neoclassical productivity measure and the Törnqvist and Fisher index number approaches assume efficient production.

Inefficiency in production provides another source or potential for measuring the total productivity change. Caves et al.[25] used a ratio of distance functions as a productivity index known as the Malmquist productivity index[34]. This measure allowed the possibility of inefficiency in the production. Caves et al.[25] did not, however, explicitly decompose productivity change into efficiency change and technical change. Färe et al.[48] first exploited the relationship between the distance function and the Farrell technical efficiency measure and computed the index with the DEA method[35].

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[33]The Fisher ideal output-oriented productivity index is the ratio of Fisher ideal output to input indices. Each of these are geometric means of Paasche and Laspeyres quantity indices.

[34]after Sten Malmqvist (1953) who first proposed construction of quantity indexes as ratios of distance functions

[35]For example distance function at time t

$$D_i^t\left(y_i^t, x_i^t\right)^{-1} = \min_{\lambda_i, \theta}$$

$$\text{st.} \quad \sum_{i=1}^{K} \lambda_i y_{im}^t \geqq y_{m,}^t \forall m$$

$$\sum_{i=1}^{K} \lambda_i x_{in}^t \leqq \theta x_{n,}^t \forall n$$

$$\lambda_i \geqq 0, \forall i$$

The distance function under CRS[36] technology is linearly homogeneous with respect to the inputs and outputs:

$$D_I^t\left(y^t, x^t\right) = \frac{y_t}{x_t} D_I^t\left(1, 1\right) \tag{50}$$

From which it follows that the TFP index can be written as

$$\frac{y_{t+1}/x_{t+1}}{y_t/x_t} = \frac{D_i^t\left(1,1\right)\ y^{t+1}/x^{t+1}}{D_i^t\left(1,1\right)\ y^t/x^t} = \frac{D_i^t\left(y^{t+1}, x^{t+1}\right)}{D_i^t\left(y^t, x^t\right)} \tag{51}$$

The right hand side of the above equation is defined as the period t Malmquist index (Caves et al.[25]). This uses the period t efficient frontier as the reference. The period $t+1$ Malmquist index is given by the ratio $\frac{D_i^{t+1}\left(y^{t+1}, x^{t+1}\right)}{D_i^{t+1}\left(y^t, x^t\right)}$. Färe et al.[48] used the geometric mean of the period t and period $t+1$ indices. They defined the Malmquist productivity index as

$$M_i\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \tag{52}$$

$$\left\{\frac{D_i^{t+1}\left(y^{t+1}, x^{t+1} \mid CRS\right)}{D_i^{t+1}\left(y^t, x^t \mid CRS\right)} \frac{D_i^t\left(y^{t+1}, x^{t+1} \mid CRS\right)}{D_i^t\left(y^t, x^t \mid CRS\right)}\right\}^{\frac{1}{2}}$$

Färe et al.[48] decomposed the Malmquist index into two components, $M_i = EFF_i \times TC_i$, where

$$EFF_i = \frac{D_i^{t+1}\left(y^{t+1}, x^{t+1} \mid CRS\right)}{D_i^t\left(y^t, x^t \mid CRS\right)} \tag{53}$$

is an efficiency change component and

[36]This follows from linear homogeneity of the distance function with respect to its arguments

$$TC_i = \left\{ \frac{D_i^t\left(y^{t+1}, x^{t+1} \mid CRS\right)}{D_i^{t+1}\left(y^{t+1}, x^{t+1} \mid CRS\right)} \frac{D_i^t\left(y^t, x^t \mid CRS\right)}{D_i^{t+1}\left(y^t, x^t \mid CRS\right)} \right\}^{\frac{1}{2}} \tag{54}$$

is a technical change component. The efficiency change component is a ratio of two distance functions, which measure a change in efficiency between period t and $t+1$. The technical change component captures the effect of a shift in the production frontier on the productivity change.

If variable returns to scale technology is assumed, the Malmquist index does not necessarily measure productivity change (Grifell-Tatje and Lovell [55]).

Bjurek [16] defined the Malmquist TFP productivity index as the ratio of output and input quantity indexes, which also allows for the variable returns to scale assumption.

4.1.4 The Finnish data set

The database consists of a plant-specific panel data on thermal electricity generation in Finland covering the period 1994-1996. The thermal generation consisted of: coal condensing, nuclear and CHP plants. The total number of plants was about 30 (depending on the year): about 25 combined heat and electricity generation plants four conventional condensing plants and two nuclear plants.

The inputs available were: labour input (measured as total hours worked per year), fuel input (aggregate of different types of fuels measured in GJ) and capital input. Three different proxies for the capital input were considered: a user cost capital input measure based on an estimate of the plant-specific machinery stocks capacity, and a capacity utilisation corrected capital input. Capacity data was only available for 1994 and 1995. The user cost input was constructed using a perpetual inventory method [37]. A depreciation rate of 10 % and a real interest rate of 4 % were assumed.

Table 4.2 input and output variables

Table 1. Outputs and Inputs

Factor	Name	Unit
Output	Electricity	TWh
Input	Labour	Hours
Input	Fuel	GJ
Input	User cost of Capital	FIM
Input	Capacity utilisation	ratio

Total generation within the 1994 sample was 44.9 TWh which represented about 75 % share of total Finnish generation in 1994.

4.2 Technical efficiency values

There were three types of generation units in the sample below: nuclear, CHP and conventional coal condensing plants. When there is an average level of water supply in the Nordic countries and it is otherwise a 'normal' year with respect to electricity demand (no extreme winter conditions) most of the coal-based condensing plants are idle. Nuclear plants on the other hand are base-load plants and are run

[37] $K_{t+1} = (1 - \delta) * K_t + I(t)$, where $I(t)$ is real investment, δ is depreciation rate. For the initial year (1990) a value was estimated using existing fire insurance values of the machinery stocks.

practically all the time. CHP plants produce electricity and heat, and the amount of electricity is related to the required heat supply (especially in industry-based plants).

Pollit [94] subdivided his sample of over 700 hundred generation plants into four categories according to load factors. The categories corresponded roughly to plants at the base-load, two intermediate loads and peak-load. Efficiency was measured in each category separately. For the Finnish sample used here, such categorisation would have produced too small sub-samples.

The Johansen definition of capacity utilisation was in terms of two distance functions or the equivalent Farrel technical efficiency scores. This measure is free of the inefficiency component that would prevail in the standard output to capacity ratio for capacity utilisation. Table 4.3. shows average capacity utilisation measures for the three different generation types included in this study .

Table 4.3 capacity ratios in different plant types

	1994		1995	
	Johansen	output/cap	Johansen	output/cap
CHP	0.672	0.523	0.719	0.497
Nuclear	0.990	0.924	0.998	0.912
Coal	0.600	0.558	0.514	0.445

The two capacity ratio measures are compared in Table 4.3. The distance function-based measure is given under Johansen, with the comparative conventional output to capacity ratio measure next to it. Table 4.3 reports averages of the capacity utilisation ratios for each of the three types of generation plants included in the sample. In all cases the output to capacity ratio gives lower averages than the Johansen measure. The nuclear plants have a very high capacity usage ratio as one would expect, and the CHP plants have a higher than the coal condensing plants.

The effect of using different proxies for the capital input was analysed by solving a one-output, three-input model with the three proxies of the capital input. The results were compared by observing how the plant-specific efficiency score rankings and their variation differed between the models. It must be emphasized, however, that model specification tests in general are not well-established in the DEA literature. One way is to use simulated confidence intervals (bootstrapping) for each efficiency score.

In the case of the user cost measure the results indicated some 'outliers' with two plants obtaining efficiency score values below 0.25, which is a rather low figure. This may be due to the poor estimates of the machinery stock capital inputs for these particular plants. If, on the other hand, generation capacities were used as the capital input the results varied less, but the average efficiency was clearly higher than with the user cost measure. Using the latter measure and constant returns to scale technology the average[38] in 1994 was 0.709 (excluding the outliers), while with the capacity capital input the average in 1994 was 0.913. When the capacity was replaced with the capacity utilisation ratio the average dropped to 0.88 in 1994 (the efficiency of one coal plant rose while that of nuclear and some CHP-plants fell). For this study the user cost measure was used as the

[38] One should not, however, stress too much the values of the averages as the DEA method is in fact 'extreme-observation-oriented' as opposed to econometric method that measures average units.

main case as this reflects the capital costs more closely than maximum generation capacity or the capacity utilisation ratio.

Technical efficiency scores are reported in Table 4.4. The technical efficiency of Finnish electricity generation was measured using a single output and three input model. The output was total electricity generated (MWh) and the inputs were labour (hours worked per year), fuels aggregate and capital (different measures). The small sample called for a compact model due to the 'degrees of freedom' problem: with a small number of units (about 30) and relatively large number of variables the identification of efficiency would not be possible.

The results indicated that in 1994 the average technical efficiency under constant returns to scale (CRS) was 0.709, or the average need for reduction of all inputs in the same proportion was 29.1 percent. Under variable returns to scale (VRS) the average technical efficiency score was 0.782 in 1994, a slightly higher value as one would expect. The ratio of the constant returns to scale and variable returns to scale scores indicates the scale efficiency (SCALE), i.e. how close the current generation is to the constant returns to scale input usage level. This was relatively high, 0.9. One can also see from Table 4.4. that the average efficiency improved steadily from 1994 to 1996. This issue is further analysed in the next sub-section.

Average technical efficiencies were also calculated for two sub-samples: industry group generators and communal generators. The former is typically a CHP plant close to a pulp and paper factory which requires heat in its processing. As some of these industries are publicly owned and some privately owned the sub-division is not the same as between public and private ownership. However, the industry group can be thought as being run more along commercial lines than the communal generators which are mainly large city generators. The differences turned out to be fairly small: in 1994 the communal plants were slightly more efficient than the industry group, while in 1995 the situation was reversed and in 1996 the communal group was again slightly more efficient.

Table 4.4. Technical efficiency scores for the whole sample 1994-1996

	All plants 1994		
	CRS	**VRS**	**SCALE**
Average all	0.709	0.782	0.900
Communal	0.663	0.750	0.891
Industr	0.651	0.749	0.859

	All plants 1995		
	CRS	**VRS**	**SCALE**
Average all	0.728	0.805	0.901
Communal	0.706	0.752	0.936
Industr	0.743	0.880	0.834

	All plants 1996		
	CRS	**VRS**	**SCALE**
Average all	0.807	0.838	0.963
Communal	0.815	0.839	0.970
Industr	0.748	0.794	0.948

As the majority of the generation plants were co-generation units (CHP) the relatively large sub-sample size of these plants allowed solving the efficiency scores for CHP plants alone. Again the scale efficiencies are fairly high, and the differences between the two sub-sample averages are fairly small. In this case, however, the total average efficiency first falls somewhat during 1994-1995 and then rises in 1995-1996.

Table 4.5. Technical efficiency scores for CHP plants alone 1994-1996

CHP-Plants 1994	CRS	VRS	SCALE
Average all	0.828	0.913	0.908
Communal	0.873	0.916	0.955
Industry	0.752	0.866	0.870

CHP-Plants 1995	CRS	VRS	SCALE
Average all	0.729	0.862	0.847
Communal	0.720	0.835	0.863
Industry	0.738	0.892	0.830

CHP- plants 1996	CRS	VRS	SCALE
Average all	0.822	0.872	0.946
Communal	0.896	0.942	0.954
Industry	0.736	0.792	0.937

One explanation for the fluctuating efficiency from year to year is change in some exogenous variables that affect the outputs or inputs. An important consideration in Nordic markets is fluctuations in hydro generated electricity in Sweden and Norway. Conventional condensing generation in Finland changes with the water supply conditions in Sweden and Norway. Factors such as the water supply or changes in demand make the identification of efficiency scores difficult, especially when trying to assess the effect of the new competitive regime on performance. However, these changes in efficiency scores occured within sub-sample, which would not be very sensitive to these particular factors. Further information could be obtained by explaining the efficiency figures with a set of feasible variables using, for example, the Tobit regression model.

4.3 Productivity changes

Productivity changes were calculated with the Malmquist productivity indices. Table 4.6 reports the total productivity index (MALM) and its two components: efficiency change (EFF) and technical change (FRO). Value of unity of these measures indicate no change in total factor productivity, in technical change, and technical change respectively. In some cases one of the components may indicate regression (value less than one) and the other component improvement (value greater than one), while the total index simultaneously indicates no change in total factor productivity.

The output and inputs used were the same as in the above case when the technical efficiencies were calculated. For example, for DMU 22 during 1994/95 there was a fall in the efficiency component (EFF=0.79) and an improvement in technical change (FRO =1.27). The overall productivity change was equal to one (MALM = 1.0).

Table 4.6. Malmquist productivity indices

	1994\1995			1995\1996		
Plant	MALM	EFF	FRO	MALM	EFF	FRO
DMU2	1.010	1.000	1.010	1.060	1.000	1.060
DMU3	1.180	1.000	1.180	0.910	1.000	0.910
DMU21	1.010	0.990	1.170	0.850	1.000	0.740
DMU22	1.000	0.790	1.270	1.030	1.250	0.820
DMU5	0.990	1.000	0.990	1.130	1.000	1.130
DMU28	0.770	1.010	1.410	1.460	0.970	0.760
DMU18	2.000	1.020	1.960	0.560	0.990	0.580
DMU23	1.160	0.990	1.340	0.980	1.010	0.810
DMU6	1.090	1.000	1.090	0.980	1.000	0.980
DMU8	0.630	1.000	0.630	1.540	1.000	1.540
DMU25	0.950	0.920	1.200	1.110	1.090	0.890
DMU9	0.940	1.000	0.940	0.990	1.000	0.990
DMU10	1.060	1.000	1.060	1.090	1.000	1.090
DMU26	1.000	0.940	2.000	1.700	1.070	0.850
DMU13	0.900	1.000	0.900	1.040	1.000	1.040
DMU27	1.130	0.810	1.370	1.480	1.230	1.110
DMU14	1.000	0.780	1.300	1.050	1.290	0.800
DMU15	0.950	0.960	0.990	1.070	1.040	1.020
DMU16	1.080	1.000	1.080	0.910	0.990	0.920
Average	1.045	0.955	1.165	1.071	1.045	0.930

For the 1994-1995 period the average Malmquist index value was 1.045 suggesting a growth of 4.5 % in the overall productivity. The average efficiency (EFF) component was 0.955 and the average technical change component 1.165.

For the 1995-96 period the average Malmquist index value was 1.071 indicating 7.1 % increase in the overall productivity. The improvement in overall productivity was mainly due to the efficiency improvement (average EFF 1.045). Technical change during this period did not show improvement .

4.3.1 Significance of the productivity changes

The basic weakness with the distance function-based productivity and efficiency calculations is that the method does not incorporate random noise. Only point estimates are provided with no information on uncertainty regarding the calculated values. To deal with this problem a bootstrap technique, originally due to Efron [34], is applied to obtain statistical precision in the point estimates regarding the Malmquist averages. The bootstrap method estimates the distribution of an estimator or test statistic by resampling the data. The database is treated as if it were the population for the purpose of estimating the distribution. Under mild regularity conditions, the bootstrap yields an approximation of the distribution of an estimator or a test statistic at least as accurate as the approximation obtained from first-order asymptotic theory.

Below, a bootstrap method proposed by Atkinson and Wilson [11] is used to construct confidence intervals for the geometric means of the Malmquist productivity indexes. Given our small sample (20 decision-making units and three time periods) the central limit theorem cannot be used for asymptotic normality assumption of the means.

For each $t = 1,..,T$ (here T=2) a sample of the means $\{M_{it}\}_{i=1}^{N}$ is observed. A confidence interval for the population mean μ_t is constructed as:

1. Compute the sample geometric means $\overline{M}_t = \left(\Pi_{i=1}^{N} M_{it}\right)^{\frac{1}{N}}$

2. For a small sample correction compute $\ln\left(\tilde{M}_{it}\right) = \ln\left(M_{it}\right)\sqrt{\frac{N}{N-1}} + \ln\left(\overline{M}_t\right)\left(1 - \sqrt{\frac{N}{N-1}}\right)$

3. Independently draw N times from the set $\left\{\tilde{M}_{it}\right\}_{i=1}^{N}$ with replacement to obtain $\left\{\tilde{M}_{it}^{*}\right\}_{i=1}^{N}$

4. Compute $\overline{M}_t^{*}(j) = N^{-1}\sum\limits_{j=1}^{N}\ln\left(\tilde{M}_{it}^{*}(j)\right)$

5. Repeat (3) – (4) J times to obtain $\left\{\bar{M}_j\left(J\right)\right\}_{j=1}^{J}$ (here J=2000)

The obtained bootstrap values $\overline{M}_t^*\left(j\right)$ can be sorted by algebraic value to construct confidence intervals for the means using the bootstrap percentile method suggested by Efron [35]. A $(1-2\alpha)\times 100$ percent confidence interval for the population mean is obtained by deleting $\alpha \times J$ values from both ends of the sorted array of J bootstrapped values and taking the endpoints of the truncated arrays as the boundaries of the confidence interval.

Figures 4.2. and 4.3. display both the averages of the Malmquist indices and the 95% ($\alpha = 0.025$) confidence intervals derived from bootstrapped (J=2000) values. The null hypothesis is that the value of the overall productivity index and of the two components is one. The figures show the confidence intervals around the null hypothesis. If the interval includes the value of 1.0 then the average does not deviate significantly from this value and hence there has not been significant change in the variable in question. The overall Malmquist index (Malm) for the period 1994/95 did not display significant productivity improvement. The observed average productivity change (1.04) was insignificantly different from unity. However, both of the components of the index, the efficiency (Eff) and technical change (TC), were significantly different from unity. Thus there was a significant fall in technical efficiency and a significant improvement in technical change in 1994-1995.

Figure 4.2. Confidence intervals for 1994/95 Malmquist index and its components (α=0.05)

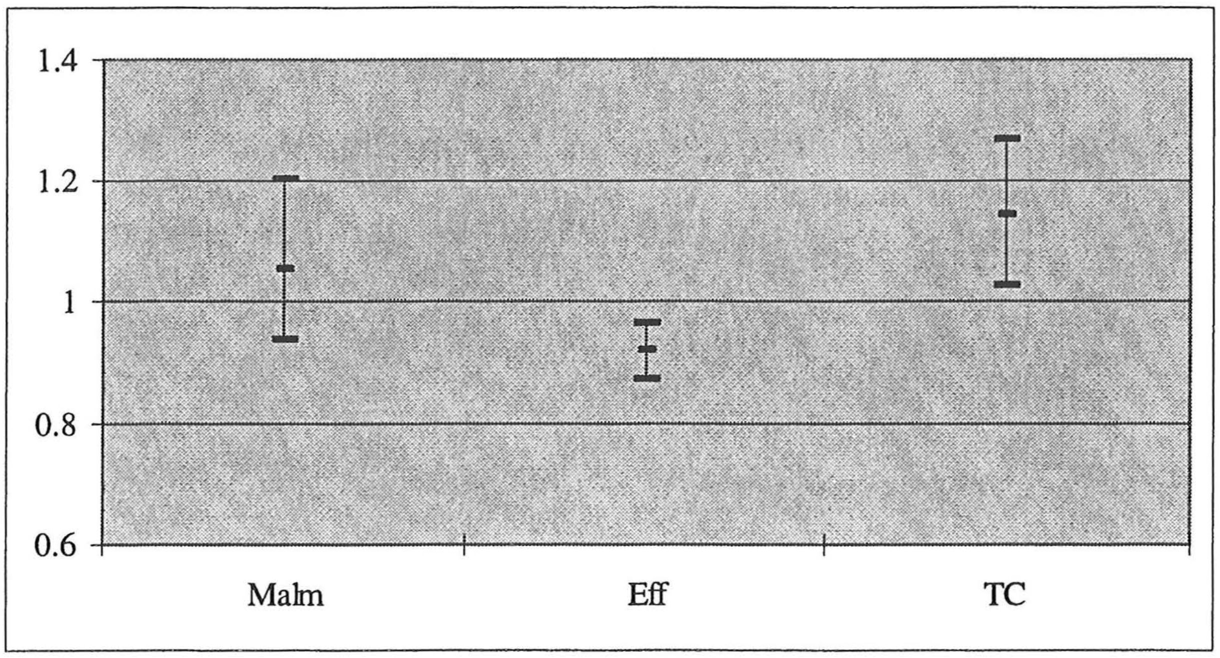
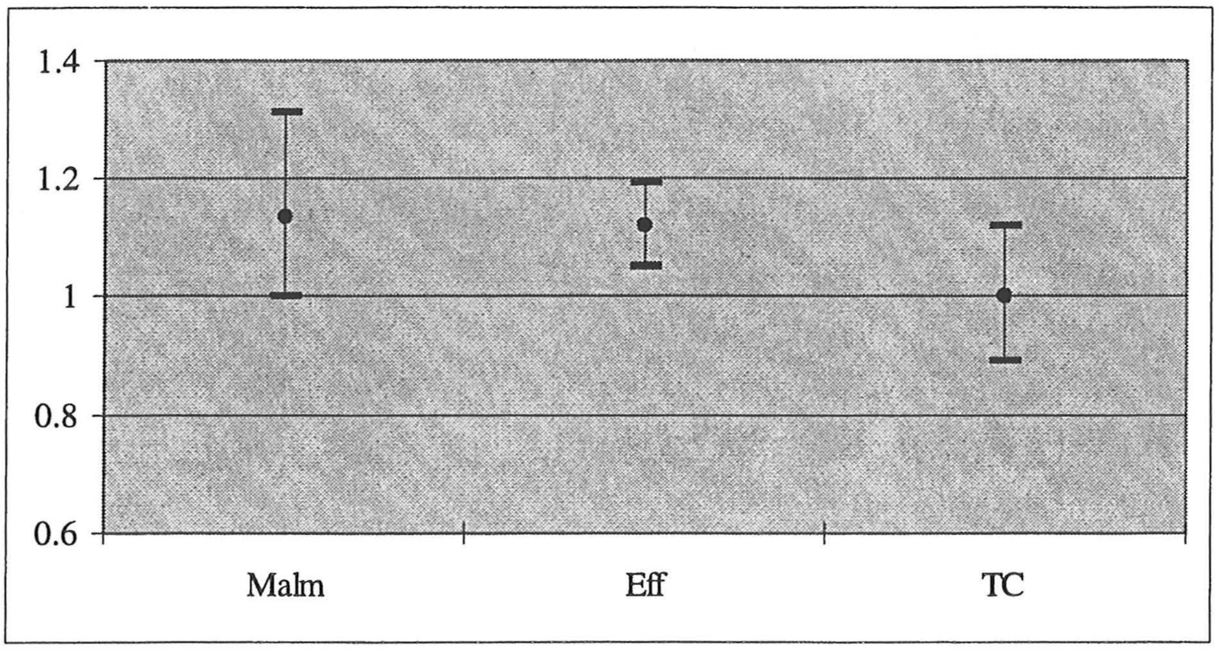


Figure 4.3 shows that for 1995-96 the overall productivity change was significant (the lower boundary is just above 1.0). The efficiency component was significantly above 1.0 while the technical change did not show improvement.

Figure 4.3 Confidence intervals for 1995/96 Malmquist index and its components



The average overall productivity increase was 7.1 % for the period 1995-96. This resulted from increased efficiency rather than technical change. The analysis reveals that aggregate electricity generation rose about 14 % between 1995 and 1996. On the input side aggregate fuel use increased by roughly 7.5 % and labour input by 3.5 %, while capital input remained more or less unchanged. The efficiency improvement was achieved by reduced use of labour and capital relative to use of fuels.

5 Conclusions

This chapter presented an analysis of different measures of technical efficiency and productivity of the Finnish thermal electricity generation. The Data Envelopment Analysis (DEA) method was used. The sample consisted of a plant-specific panel data from the period of 1994-1996 with two potential outputs (electricity and heat) and three inputs (labour, fuels and capital) to describe the generation process.

Technical efficiency scores indicated that the generation plants were relatively efficient. In 1994 the average technical efficiency value under constant returns to scale technology assumption was 0.709, i.e. there was an average need of 29.1 percent reduction of all inputs to reach 100 percent technical efficiency. Under variable returns to scale (VRS) the average technical efficiency score was 0.782 in 1994, a slightly higher value as one would expect. A ratio of the constant returns to scale efficiency score value to variable returns to scale efficiency score value is interpreted as a measure of scale efficiency, i.e. how close observed output level is to the constant returns to scale level.

Productivity analysis showed that for the 1994-1995 sub-period the average overall Malmquist index value was 1.045, suggesting a growth of 4.5 % in total factor productivity. For the 1995-96 sub-period the growth was even higher, at 7.1 %. The improvement in productivity turned out to be due to improved technical efficiency. The bootstrap technique due to Atkinson and Wilson [11] was applied to the Malmquist average scores to construct the 95 % confidence intervals. It turned out that at the 95 % confidence level the overall Malmquist index average did not display significant productivity improvement during 1994-95, whereas during the 1995-96 period the overall productivity change was significant.

6 Technical efficiency and productivity of Finnish electricity distribution in 1996-1998

The introduction of competition in the electricity sales and generation sectors has also increased pressures to boost efficiency in the regulated distribution and transmission sectors. Regulatory schemes providing incentives to attain efficient production have been developed and applied to networks. Empirical studies have indicated that there is a relatively large efficiency improvement potential in the Nordic electricity distribution sectors. Hougaard [64], for example, found that the Danish electricity distribution sector had an average technical inefficiency in the range of 20-40 % (in terms of required input reduction for technical efficiency) depending on the model used. The Norwegian electricity distribution sector has been shown to possess an average input improvement potential of about 30 %, Langset and Torgersen [77].

The Nordic electricity market authorities are devoting increasing interest to assessing the efficiency of the distribution sectors. Norway has gone so far as to include an efficiency component in the regulatory rule: the permitted income-caps of the distribution companies depend partly on the company-specific cost-efficiency values. The Norwegian regulatory system changed in 1997 from a rate of return regulation to a more incentive-based[39] income-cap regulation. The electricity distribution (and transmission) companies are now subject to pre-determined income caps by the regulator, Norges Vassdrags og Energiverk (NVE). The permitted income from network operation depends partly on a company-specific productivity component that involves assessment of company-specific cost efficiency. Companies that turn out to be cost-ineffective will have a lower future income allowance than the cost efficient firms.

Although Finland and Sweden do not apply explicit regulatory rules in the monitoring of their distribution sectors, they have started to develop models to assess the productive efficiency of regulatees. Decision-making for dealing with possible complaints of over-pricing the network services requires such analysis tools. Both the Finnish and Swedish electricity market regulators have initiated efficiency

[39] Another example of an incentive-based regulatory scheme is the RPI-x rule adopted in the UK. This rule restricts price development to the retail price index (RPI) change and gives 'surplus' income to firms that have higher productivity growth (x) than the pre-determined level, set by the UK regulator.

evaluation studies of their distribution sectors.

This chapter analyses the technical efficiency and productivity of the Finnish electricity distribution sector during the period 1996-1998. While technical efficiency is a milder criterion for productive efficiency than cost-efficiency, it does not require data on input and output prices (which especially for capital input are hard to formulate). The database for this study consists of fairly extensive input-output data covering all Finnish distribution companies during 1996-1998. The two sub-periods (1996-97 and 1997-98) allowed measurement of total factor productivity changes.

This rest of the chapter is organised as follows: the following section presents the main features of the Finnish electricity distribution sector. Section 5.2 presents potential variables for inclusion in the modelling of electricity distribution production. Section 5.3. presents the technical efficiency scores for the Finnish distribution sector and section 5.4. reveals the productivity changes.

6.1 Electricity distribution in Finland

The new electricity market act established a new regulatory body, the Electricity Market Authority[40], as an independent expert body subordinate to the Ministry of Trade and Industry and acting as the main electricity market regulator in Finland. Its responsibilities include:

- granting, cancelling or amending network licences
- supervising network pricing

[40]Energy Market Authority as of 1 August 2000.

- assessing efficiency of the network companies

The new Electricity Market Act specifies a number of requirements for network operators have to adhere to. Among these are that network operators must sell their services (connection, transmission and metering) at 'reasonable' and non-discriminating (over geographic areas or between customer types) prices.

The regulator investigates possible over-pricing charges on a case-by-case basis, rather than using explicit regulatory rules. The regulatory framework currently resembles a yardstick competition where performance is measured between comparable utilities. The electricity market authority assesses costs and rates of returns of utilities that fall within its powers of investigation. In its first case, the authority ruled that the distribution company concerned did earn too high a rate of return by over-pricing its distribution network services. Consequently the utility has to return these excessive profits back to its customers in the form of future price cuts. Currently over 30 cases of alleged monopolistic pricing are under the electricity market authority's investigation. The regulator has indicated that it will develop means to assess the efficiency of the distribution companies in order to widen its scope for assessment.

Efficiency measures that take into account all relevant inputs and outputs are required to complement the rate of the return evaluation.

Electricity networks can be divided into two or three[41] different levels, according to voltage level used. A national grid is a high voltage (in Finland 440 kV) network and typically run by one regulated grid company (Fingrid Plc in Finland). Low and medium voltage lines (0.6 kV - 70 kV) make up a distribution network typically run by several (110 in Finland) distribution companies which are local monopolies. The distribution network connects the grid and end users of electricity.

Finland's electricity distribution network consists of low-voltage (0.4 kV) and medium voltage lines (0.6-70 kV). The two main (in terms of line lengths) voltage levels used are 0.4 kV and 20 kV.

The 110 distribution companies are monopolies within the specific geographical area they are licenced for. Their ownership structure is divided between public companies ($\approx$ 50%), public utilities ($\approx$ 25%) and private companies ($\approx$ 25%). In addition there are some economic co-operatives. Recent mergers and acquisitions have decreased the number of companies in the late 1970s there were over 200 distribution companies in Finland.

There are large disparities in terms of both distribution area and customer dispersion. In northern and eastern parts of Finland electricity distribution areas are large but population densities low, while urban areas, especially in the south, are characterised by relatively short transmission distances and high customer densities.

[41] In addition to distribution and the national grid, the regional network can be separated as one level of electricity network. The regional network is not, however, asclearly defined as distribution and the grid. In Finland it consists of separate 110 and 220 kV lines from large industrial units to the grid.

In this chapter, urban and rural companies are divided by network units per number of customers in the distribution area. A network unit is a weighted sum of low- and medium voltage lines and number of transformers, with one kilometer of low voltage areal line being used as the base unit (equal to one). The two samples consisted of about 65 rural and 45 urban companies.

6.2 Outputs and inputs in electricity distribution

The electricity distribution business involves numerous outputs and inputs. The following sub-sections present some fundamental outputs and inputs that characterise the production of network services.

6.2.1 Outputs

A variable is categorised as an output when an increase in its quantity requires more resources or reduction of other products by the producer. Below are reviewed some fundamental outputs that should be considered when modelling electricity distribution production.

6.2.1.1 Energy delivered

The main output in the electricity distribution business is the amount of energy delivered to end users. Energy delivered is included as an output in all efficiency studies (known to this author) concerning this sector. In some studies total energy delivered is divided into two separate outputs: low voltage and high voltage outputs.

6.2.1.2 Customers

Number of customers is another typical output variable in studies analysing the productivity and efficiency of the electricity distribution sector. An increase in the number of customers requires increased resources (metering, billing etc.) and so is considered as an output. Again, in some studies this variable is sub-divided by voltage levels (low and high voltage customers). There is, however, a problem with the division of customers into low- and medium voltage groups. Usually the small voltage customers (households) also use medium voltage lines indirectly, so there may be a problem of identifying which customers belong to which group.

6.2.1.3 Geographical area served

The longer the distance of electricity transmission, the larger the costs of delivery. The longer the distance the higher the voltage of the level lines required in order to minimise costs of transmission losses (that are related to square of the current). This calls for capturing the distance of electricity delivery when assessing efficiency of the distribution.

The size of the distribution area may not be a very accurate proxy for the delivery distance. Typically a large distribution area is sparsely populated and the network may be concentrated in a much more localised area.

Also, a longer delivery distance implies an increased resource requirement or lower level of other outputs, which means that the variable describing it should be specified as an output variable.

Langset and Torgersen [77] used distribution line length as the output variable to capture differences in distribution distance (and topography) between the Norwegian utilities. The use of distribution lines as output may, however, be problematic as these are not strictly exogenous to the utilities. Furthermore, Førsund F. and Kittelsen [42] point out that line length output would be highly correlated with used capital input. These authors instead use a distance index to capture the geographical area served by Norwegian utilities. The index is based on the average travelling time to the municipal centres.

In this chapter the total number of road kilometers per distribution area was used as a proxy variable to capture the delivery distance. Like the distance index, this variable is also exogenous to the utilities and is highly correlated to the line length variable.

6.2.1.4 Other outputs

Pollitt [94] used maximum demand as an output to consider the load profile effect on the utilities. Two utilities required to deliver the same amount of energy may face a quite different resource requirement because the two loads differ in their time profile; one may have a high and short peak demand, while the other may face a flatter load profile, i.e. peak demand with longer duration.

Førsund F. and Kittelsen [42] argue that the information contained in maximum power is in fact well captured by the interaction of aggregate energy delivered and number of customers. This is because average energy per customer is correlated with the number of residential household customers as a share of total customer base, and this again is correlated with peak power compared to average power level.

Pollitt [94] used the sizes of the distribution areas as output, although this variable may overestimate the implied difficulty of electricity distribution in a large area, as was noted above.

6.2.2 Inputs

Inputs are typically divided between labour (e.g. hours worked or number of employees), capital (e.g. line lengths, transformer capacities), distribution losses and other cost components.

6.2.2.1 Labour

In this study labour is measured by the total number of employees in a distribution utility. Another possibility would be to use average wage expenditures or hours worked per year.

6.2.2.2 Capital

The most important and also the most difficult input to measure in electricity distribution is the capital input. Physical capital input typically consists of line lengths and transformer capacities. Capital can also be measured in monetary terms. The use of, say, book value-based capital is, however, problematic due to differences in depreciation between utilities.

6.2.2.3 Energy losses

Energy losses are included as an input since they add to costs. Loss data are, however, problematic in that they are difficult to measure and, at least in Finland, the way they are calculated differs between utilities. In our database energy losses displayed significant yearly fluctuation, so the input was dropped for the productivity change measurement.

6.2.2.4 Other inputs

These are typically materials and services inputs, that can be broadly categorised as non-labour operation and maintenance inputs.

6.2.3 Exogenous variables

Exogenous or 'environmental' factors of production (variables outside the control of managers) may fundamentally affect the assessment of distribution utilities' performance, so it is important to take these into account in efficiency and productivity analysis. Such factors can be dealt with by dividing the total sample into sub-samples if the effect of the environmental factor on productive efficiency is known, and the sample can be ranked by these effects.

Here, the geographical area has been taken into account by incorporating a proxy output variable in the model that represents the distance of distribution.

Other potentially important environmental factors that may affect electricity distribution include local weather conditions (snow, coastal area corrosion and erosion etc.), topography, and density of lakes (may be relevant in Finland). The problem is of course to devise good proxy variables for such factors.

Table 5.1 presents outputs and inputs that have been used in other studies analysing efficiency or productivity in electricity distribution.

Table 5.1 Output and input variables in electricity distribution studies

Ouput / Input	Number of customers	Energy deliver	Distance-index	Max load	Area size	Length of lines
Labour	✹ ○ □ ❆	✹ ○ ■ □ ❆	✹	❆	❆	□
Losses	○	○ □				□
Capital ($)	✹	✹ ■ □	✹			□
Length of lines	○ ❆	○ ■ ❆		❆	❆	
Transformer capacity	○ ❆	○ ❆		❆	❆	
Materials ($)	✹	✹	✹			

❆ = Pollitt
✹ = Førsund ja Kittelsen
□ = NVE
○ = Hjalmarsson & Veiderpass
■ = Weyman-Jones

6.3 The Data

The data set for this study consisted of fairly extensive input-output data on electricity distribution including all distribution companies in Finland for period 1996 to 1998. The variables available appear in Table 5.2.

Table 5.2. Outputs and inputs for the Finnish study

Outputs/environmental variables	Inputs
Energy delivered (low and high voltage)	Number of employees
Number of customers (low and high voltage)	Circuit length
Road-mileage per distribution area	Transformer capacity
Maximum demand	Energy losses
	Delivery interruptions

Thus potentially six outputs (if voltage level separation done) and six inputs were available. The summary statistics of the data in Tables

5.3. and 5.4. reveal the fairly large degree of variation within the data set. This reflects the disparities in the sizes of the distribution companies and areas.

Table 5.3 Summary statistics for the inputs

Inputs 1996

	No. of emplyees	Circuit length low voltage	Circuit length high voltage	Energy losses	Transformer capacity	Delivery interruptions
mean	60.70	1926.38	1220.74	14.00	180754.79	4.62
deviation	82.28	2857.13	2098.82	19.50	273926.92	5.37
Min	2.50	81.00	41.00	0.13	5700.00	0.11
Max	521.50	15572.00	10913.00	124.34	2137255.00	44.00

Inputs 1997

	No. of emplyees	Circuit length low voltage	Circuit length high voltage	Energy losses	Transformer capacity	Delivery interruptions
mean	58.83	1950.21	1234.66	15.41	189930.45	4.14
deviation	78.66	2897.20	2126.49	19.89	280803.94	3.58
Min	1.00	81.00	41.00	0.00	5750.00	0.15
Max	511.00	15433.00	11021.00	123.50	2163900.00	21.48

Inputs 1998

	No. of emplyees	Circuit length low voltage	Circuit length high voltage	Energy losses	Transformer capacity	Delivery interruptions
mean	57.02	1986.53	1256.19	16.81	194642.60	4.17
deviation	70.72	2964.07	2147.02	21.23	287029.09	3.97
Min	2.50	81.00	41.00	0.70	5800.00	0.02
Max	406.00	15547.00	11076.00	131.00	2226500.00	18.00

Table 5.4 summary statistics for the outputs

	Outputs 1996				
	Energy delivered low voltage	Energy delivered high voltage	Customers low voltage	Customers high voltage	Road-mileage
mean	261.90	191.11	26336	25	715.06
Standard deviation	336.52	573.61	40006	56	1258.03
Min	8.20	0.00	775	0	13.30
Max	1998.02	5003.67	302970	503	6097.20

	Outputs 1997				
	Energy delivered low voltage	Energy delivered high voltage	Customers low voltage	Customers high voltage	Road-mileage
mean	265.21	113.61	26328	26	718.84
Standard deviation	345.15	248.74	39959	57	1263.33
Min	7.00	0.00	767	0	13.30
Max	2035.70	2032.30	308322	508	6097.20

	Outputs 1997				
	Energy delivered low voltage	Energy delivered high voltage	Customers low voltage	Customers high voltage	Road-mileage
mean	278.39	136.20	26835	28	724.86
Standard deviation	360.25	323.22	40504	62	1267.79
Min	8.30	0.00	761	0	13.30
Max	2107.00	2862.10	311368	567	6097.20

Correlation coefficients between the variables are shown in Table 5.5 for 1998 data only as these did not change much between the years.

Table 5.5 Correlation coefficients in 1998

	Energy d.	Customer	Road km	losses	Lines km	labour	transformer
Energy d.	1.000						
customer	0.982	1.000					
Road km	0.375	0.423	1.000				
losses	0.923	0.942	0.612	1.000			
Lines km	0.543	0.601	0.935	0.755	1.000		
labour	0.912	0.939	0.621	0.938	0.765	1.000	
transformer	0.969	0.977	0.451	0.936	0.611	0.934	1.000

The variable 'Energy d.' refers to total energy delivered, 'Customer' to total number of customers, losses' to delivery losses, 'Road km' to length of roads per distribution area, 'Lines km' to length of distribution lines, 'labour' to number of employees and transformer to transformer capacity. It is notable that the road kilometer variable is highly correlated with the line length variable, which has also been used as an output to capture differences in distribution distances.

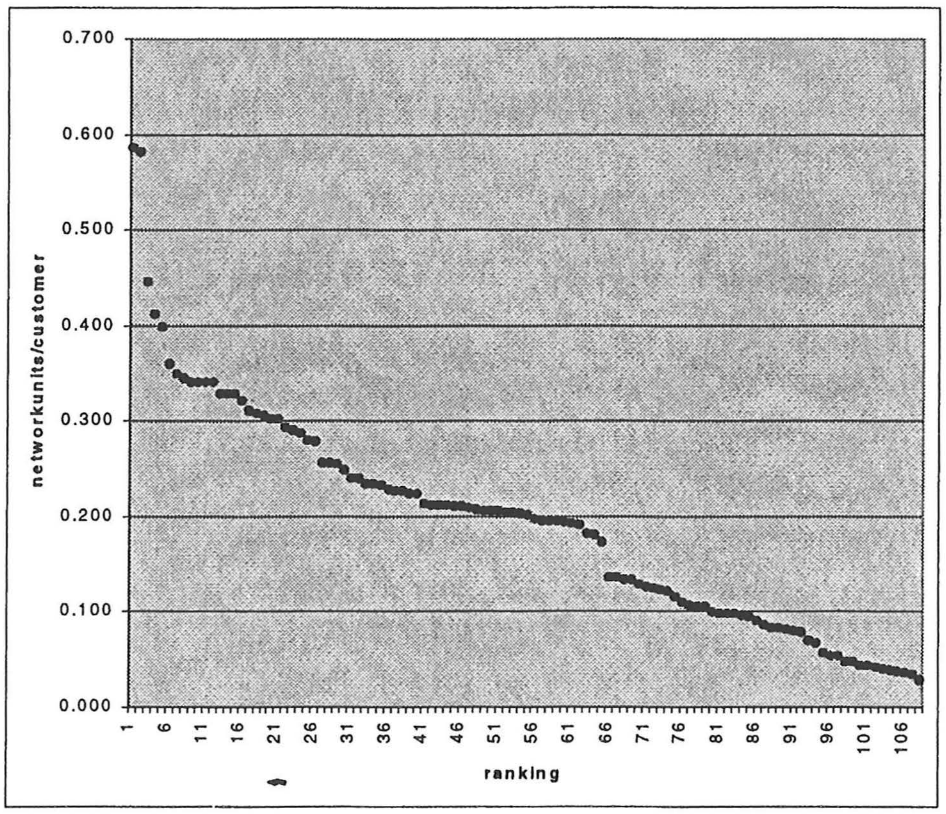
6.4 Technical efficiency results

Technical efficiency is measured using input-oriented DEA models. Several model specifications were solved to gather information on the variation of relative efficiency rankings of the distribution companies under different model specifications. Differences in the efficiency rankings among various model versions were tested with the non-parametric Mann-Whitney U-test.

In all cases the total sample was also subdivided into different categories: rural and urban distribution companies and large vs. small companies. Company size was determined by total energy delivery and the division point was 160 GWh per year, roughly the median value in the sample.

The rural-urban categorisation was done by relating network units to number of customers. A network unit is a weighted sum of low and high voltage lines and number of transformers. When the ratio of network units to number of customers is plotted against its ranking the resulting curve breaks at the value 0.154, as seen from the figure below, and this was chosen as the criteria for rural-urban division.

Figure 5.2 distribution of the network units



The resulting two samples were roughly equally-sized: the rural sample had about 65 units and the urban about 45. Technical efficiency values were calculated for each sub-sample separately. The results were also 'checked' by observing how the sub-categories differed within the total sample, i.e. technical efficiencies were calculated for the total sample before determining whether rural or urban companies performed better.

6.4.1 Model 1

Model 1 represents a relatively detailed modelling of the variable structure. Energy delivery, number of customers and line lengths are separated by the voltage level as their own variables. The model consists of five outputs (low- and high voltage delivery, low- and high voltage customers and road km) and six inputs (labour,low- and high voltage line length, transformer capacity, energy losses and delivery interruptions).

Table 5.6. Model 1 results

	1996			1997			1998		
	CRS	VRS	Scale	CRS	VRS	Scale	CRS	VRS	Scale
Model 1	0.92	0.95	0.98	0.89	0.92	0.97	0.93	0.94	0.98
Min	0.65	0.65	0.71	0.56	0.68	0.78	0.59	0.69	0.83
No. of efficient	47	48	62	38	41	45	49	60	58
Rural	0.98	0.98	0.99	0.97	0.98	0.99	0.98	0.98	0.99
Urban	0.95	0.97	0.99	0.93	0.97	0.96	0.95	0.98	0.98
Large	0.94	0.97	0.97	0.93	0.96	0.97	0.95	0.98	0.98
Small	0.97	0.98	0.99	0.99	0.99	0.99	0.96	0.98	0.98

The number of efficient units relative to total number of units (106-108) is very high with this model, as reflected in the high average technical efficiencies. Based on the very high average efficiencies, it is safe to say that this model suffers from lack of degrees of freedom to identify efficient units from inefficient ones; the number of units relative to total number of variables is too small.

In Table 5.6 the average technical efficiency scores for the total sample are reported in the first row. In 1996 the average with the constant returns to scale (CRS) technology assumption was 0.92. The equivalent values for 1997 and 1998 were 0.89 and 0.93 respectively. The next four rows report the efficiency values obtained from the two sub-categorisation exercises: urban-rural and small-large company. The rural companies did a little better than the urban ones, as did the smaller compared to the large firms.

6.4.2 Model 2

Model 2 represents a more compact modelling than model 1. Voltage levels were aggregated and the delivery interruption input variable was omitted. The model consists of three outputs (energy delivery, total number of customers and road km) and four inputs (labour, total line length, transformer capacity and energy losses).

The results below indicate lower averages for technical efficiencies: 0.84 in 1996, 0.77 in 1997 and 0.84 in 1998 with CRS technology assumptions. The averages indicate a need to reduce inputs by 16-23 % to achieve full technical efficiency. The worst performers had about a 50 % input reduction requirement for efficiency. Also, rural companies were more efficient than urban ones. The rural company sub-sample was slightly larger (about 65 units) than the urban one (about 45 units), which reinforces the conclusion.

Table 5.7 Model 2 results

	1996			1997			1998		
	CRS	VRS	Scale	CRS	VRS	Scale	CRS	VRS	Scale
Model 2	0.84	0.87	0.97	0.77	0.82	0.94	0.84	0.84	0.96
Min	0.47	0.51	0.69	0.42	0.43	0.70	0.50	0.54	0.70
No. of efficient	21	33	21	16	30	28	22	39	28
Rural	0.92	0.95	0.97	0.91	0.94	0.97	0.92	0.95	0.98
Urban	0.86	0.89	0.97	0.82	0.84	0.97	0.81	0.85	0.94
Large	0.87	0.90	0.96	0.85	0.89	0.95	0.88	0.93	0.95
Small	0.90	0.93	0.97	0.89	0.94	0.95	0.89	0.94	0.95

It seems also that small companies (by total energy delivery) were more efficient than large ones, although the differences were smaller than with the urban-rural categorisation. Given that scale efficiencies were high one would not expect large differences in efficiencies with respect to the level of output.

6.4.3 Model 3

Model 3 included the voltage level separation in energy delivery, and customer and line length variables, but the 'environmental' output variable, road kilometers, was omitted. This model resembles, in fact, the one used by Hjalmarsson and Veiderpass [61] for Swedish data. There are four outputs (low- and high voltage energy delivery and low- and high voltage customers) and five inputs (labour, low- and high voltage line length, transformer capacity and energy losses).

The number of efficient units dropped to nearly half of that in model 1. Further sensitivity analysis with model 1 indicated that the fall in efficiency was mainly due to omission of the road kilometer variable, not to the omission of the delivery interruption variable.

Table 5.8 Model 3 results

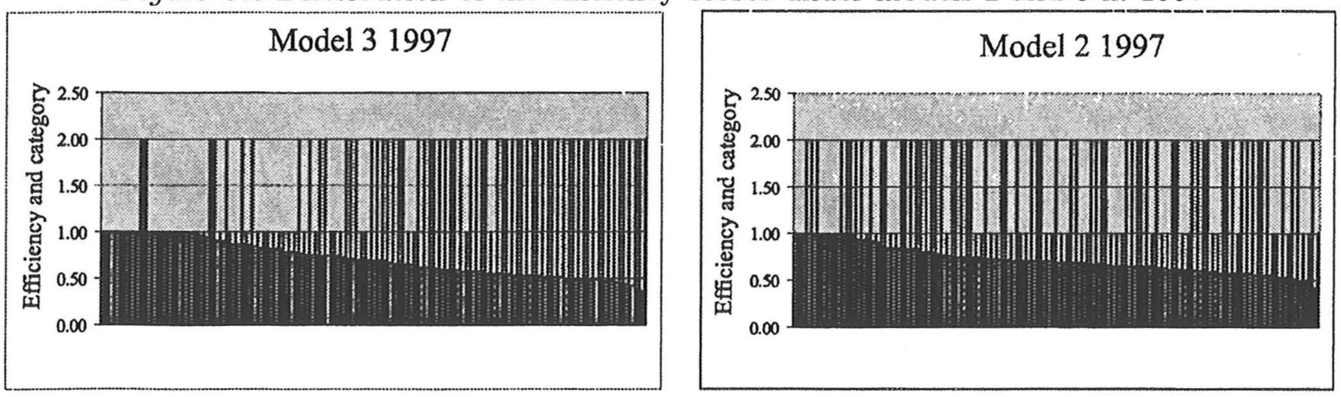
	1996			1997			1998		
	CRS	VRS	Scale	CRS	VRS	Scale	CRS	VRS	Scale
Model 3	0.83	0.88	0.95	0.71	0.79	0.90	0.84	0.88	0.95
Min	0.48	0.59	0.70	0.36	0.38	0.49	0.45	0.60	0.66
No. of efficient	23	33	30	17	25	24	23	35	40
Rural	0.90	0.95	0.95	0.88	0.95	0.93	0.94	0.96	0.97
Urban	0.93	0.94	0.98	0.87	0.90	0.96	0.92	0.95	0.97
Large	0.88	0.91	0.97	0.74	0.82	0.91	0.89	0.92	0.97
Small	0.88	0.92	0.96	0.74	0.82	0.91	0.9	0.9	0.9

The figures display an asymmetric efficiency score distribution between rural and urban companies.

The figures below illustrate efficiency scores in decreasing order and the urban-rural categories superimposed onto the same picture. The urban-rural category label was defined so that 1 indicated an urban and 2 a rural company. The figures show constant returns to scale efficiency scores for 1997 (1996 and 1998 showed similar results).

The left-hand display of Figure 5.3, indicating the model 3 results, shows how the category label 2 is skewed towards the most inefficient units, while the right display, indicating the model 2 results, shows a fairly evenly distributed distribution of efficiency between the two categories. It seems then that the road kilometer variable is important, as it evens out differences in the rural-urban distribution areas.

Figure 5.3 Distribution of the efficiency scores under models 2 and 3 in 1997



6.4.4 Model 4

Model 4 consists of three outputs (energy delivery, total number of customers and road km) and three inputs (labour, total line length, transformer capacity). The model is thus the same as model 2, but with energy losses omitted.

Table 5.8 Model 4 results

	1996			1997			1998		
	CRS	VRS	Scale	CRS	VRS	Scale	CRS	VRS	Scale
Model 4	0.76	0.81	0.94	0.71	0.76	0.93	0.80	0.84	0.95
Min	0.46	0.51	0.61	0.37	0.38	0.60	0.45	0.49	0.67
No. of efficient	11	23	11	12	25	12	14	28	14
Rural	0.88	0.92	0.96	0.86	0.91	0.95	0.92	0.95	0.97
Urban	0.82	0.85	0.97	0.75	0.78	0.97	0.83	0.85	0.98
Large	0.83	0.89	0.94	0.79	0.85	0.93	0.84	0.90	0.94
Small	0.87	0.91	0.96	0.86	0.92	0.94	0.87	0.92	0.94

Average technical efficiency under CRS technology was 0.76 in 1996, 0.71 in 1997 and 0.8 in 1998. As in the earlier cases rural companies tended to perform better than urban ones. Further sensitivity analysis of the results with respect to model specification is presented below in terms of company-specific technical efficiency rank-orderings.

6.4.5 Model selection

There are no well-established specification test procedures for DEA-models. The deterministic modelling approach calls for sensitivity analysis of the effects of model structure on individual efficiency rankings. Valdmanis [112] uses the Mann-Whitney test on differences in rankings of decision-making units obtained from different model specifications. Valdmanis calls for a robust model structure with respect to differences in efficiency categorisation due to small changes in the input-output structure. Testing rank-orderings is, however, problematic. Kittelsen [71] points out that one fundamental difficulty is that nested models do not produce identically and independently distributed efficiency scores. He showed with Monte Carlo simulations, however, that dependence of two efficiency scores from different models tends to decrease the value of the test statistics, leading to under rejection of a true null hypothesis. A bias effect, originating from the fact that they are not identically distributed, works in the opposite direction, partially or wholly off-setting the under-rejection.

Model 1 was dropped due to lack of degrees of freedom leading to problems of identifying efficient units from inefficient ones. Model 3 results suffered from uneven distribution of the efficiency values between urban and rural companies due to omission of the distance variable (road kilometer length).

Thus, the model-specification analysis was restricted to three versions of model 2, that is, the model with three outputs (energy delivery, total number of customers and road km) and four inputs (labour, total line length, transformer capacity and energy losses). The versions were model 2, model 2 with delivery interruption input variable, and model 2 without the loss variable (model 4).

Solved efficiency scores were compared by the implied ranking of the companies according to their efficiency. The Mann-Whitney U-test was used, with correction for the fact that some companies had the same efficiency score (especially those with score one). The correction is shown in, Siegel [102], and slightly raises the z-variable value implied by the test. The null hypothesis is that the two rankings compared come from the same population and that there is no statistical difference between them. The Mann-Whitney U statistic can be assumed to be normally distributed when the sample sizes are over 20. Table 5.9 reports standardised U-statistics for tests of differences in efficiency rankings between the model versions.

Table 5.9 Mann-Whitney U-statistics

	1996	1997	1998
Model 2 vs. model 4			
Standardised Normal	2.16	3.63	2.41
Model 2 vs. model 2 with interuption			
Standardised Normal	0.81	1.94	1.81

The model 2 vs. model 4 test statistic value in 1996 was 2.16, which is not significant at the 95 % confidence level. The critical p-value for 2.16 is 0.0154, which is below the rejection level (5%). In fact only the 1997 model 2 vs. model 4 test statistic value of 3.63 is large enough to reject the null hypothesis that the efficiency rankings implied by the two models are not different.

One can interpret the above 'model-specification' tests to indicate that omission of the energy loss input variable from model 2 or inclusion of the energy delivery input variable in model 2 does not change the efficiency results substantially. As the loss data were considered somewhat unreliable (being difficult to measure) model 4 was preferred to model 2. Thus model 4 was used as the basis for measuring of the productivity development.

6.5 Productivity development 1996-1998

Productivity was measured with the Malmquist index for two subperiods; 1996-1997 and 1997-1998.

Table 5.91 Average changes in the outputs and inputs

Period 1996-1997	Outputs		Inputs		
variable	Energy delivered	Customers	Labour	Line length	Transformers
Average change	-6.442	-0.078	-3.080	0.722	2.753
Period 1997-1998	Outputs		Inputs		
variable	Energy delivered	Customers	Labour	Line length	Transformers
Average change	4.928	1.343	-2.121	-0.152	1.430

Table 5.91 shows the average yearly percentage changes in the individual outputs and inputs. During 1996-1997 the outputs (energy delivered and number of customers) decreased, as did the labour input. The next period witnessed an increase in the outputs and a fall in labour and line length inputs.

Malmquist indexes were solved with DEA model 4, assuming constant returns to scale technology. In the period 1996-1997 the average for the Malmquist index was 0.982, indicating a 1.8 % fall in total factor productivity. The two components of total productivity change, efficiency and technical change components, indicate that during 1996-1997 efficiency increased by one percent and the technical change fell about three percent.

In the 1997-1998 period total factor productivity increased slightly, by 0.4%, which was due to a rise in efficiency (0.5 % increase). The technical change component was close to one.

Compared to other Scandinavian studies the productivity development seems moderate. Karlsson [69] used the NVE-model and measured total factor productivity with the Malmquist index for the Norwegian electricity distribution sector in the period 1994-1995; the total factor productivity change was 5 %. The model used was similar to the above model 4, except it included energy losses as an input. Førsund and Kittelsen [42] studied total factor productivity development in Norway between 1983 and 1989. The average value for the Malmquist was 1.12, which corresponds to 1.9 % annual productivity growth. The efficiency component equalled 1.006 and the frontier shift component 1.108. As the authors note, there was very high variation within the solved productivity values across distribution companies. The highest increase in productivity in the study was 245 % , due to a large fall in energy loss level for the company in question. In this study losses were omitted due to their large fluctuations from year to year.

6.5.1 Confidence intervals for the productivity changes

A bootstrap technique, originally due to Efron [34], was applied to obtain confidence intervals for the Malmquist averages. The bootstrap is a method for estimating the distribution of an estimator or test statistic by resampling the data. The database is treated as if it were the population for the purpose of estimating the distribution. Under mild regularity conditions, the bootstrap yields an approximation for the distribution of an estimator or a test statistic which is at least as accurate as that obtained from first-order asymptotic theory.

Below, a bootstrap method proposed by Atkinson and Wilson [11] is used to construct confidence intervals for the geometric means of the Malmquist productivity indexes.

Table 5.92 Confidence intervals for productivity averages

Malmquist-index	96/97	97/98
Lower limit	0.978	0.973
average	0.982	1.004
Upper limit	1.072	1.010
Efficiency component	96/97	97/98
Lower limit	0.996	0.989
average	1.009	1.005
Upper limit	1.010	1.011

In all cases the 95 % confidence intervals cover unity, so the null hypothesis of no significant change cannot be rejected.

6.5.2 Conclusions

This chapter has analysed the technical efficiency and productivity growth of the Finnish electricity distribution sector during the period 1996-1998.

Earlier studies on the Swedish and Norwegian electricity distribution sectors found fairly rapid productivity growth rates. Hjamarsson and Veiderpass [61] found productivity growth in Swedish electricity distribution during 1970-1986 to be fairly rapid; average annual growth for the 17-year period was 5%.

In Norway productivity grew by 1.9 % between 1983 and 1989 (Førsund and Kittelsen [42]), while during the period 1994-1995 productivity growth was 5 % (Karlsson [69]). The Finnish productivity growth seems modest by comparison. Total factor productivity fell in 1996-1997 by 1.8 %, and rose by 0.4 % in 1997-1998. In both subperiods efficiency improved slightly. Simulated confidence intervals showed that these changes were not statistically significant (at the 95% level).

A possible reason for the poorer Finnish productivity performance, especially compared to the Norwegian distribution sector, is that energy losses were omitted in this study. When these were included the average improvements were greater, due to some very large falls in delivery loss levels, which were nevertheless considered to reflect the uncertain quality of loss data.

Average technical efficiency under CRS technology was 0.76 in 1996, 0.71 in 1997 and 0.8 in 1998. In Norway it was 0.78 in 1994 and 0.83 in 1995 with a similar model (see Karlsson [69]).

Overall, the conclusion is that in Finland distribution companies were scale efficient, rural companies were more efficient than rural ones, and productivity growth was fairly modest during 1996-1998.

7 Conclusions

This monograph has analysed the effects of Nordic electricity market deregulation on the efficiency of electricity pricing in the Nordic wholesale markets and on productive efficiency in the Finnish electricity market. The main object was to quantify the possible efficiency changes originating from the recent market reforms. Two different approaches were taken, one involving analysis of different market equilibria in the electricity spot markets by using numerically solved oligopoly models (the marginal cost pricing representing the efficient benchmark), the other involving measuring the performance of Finnish electricity generating and distribution companies by a non-parametric data envelopment analysis (DEA) method (with technical efficiency being the benchmark).

The introductory chapter presented the main types of reform models that have been applied in electricity market deregulation. This was followed by a review of previous studies on the analysis of deregulated electricity markets that have focused on the efficiency of the competition. Next, in sections 1.6 and 1.7 the structure of the three electricity markets that were analysed, Norway, Finland and Sweden, were presented in more detail.

Chapter two analysed competition in the Finnish electricity market. The model developed for the analysis extended a model[42] developed by Andersson and Bergman [6] who analysed the deregulated Swedish electricity market outcome.

The results indicated that the degree of competition in the Finnish electricity market alone may not be sufficient to guarantee more efficient whole-sale pricing of electricity (when the 1994 base year price level is used as the criterion). In the Cournot equilibrium the market equilibrium price rose from FIM 160 per MWh in the base year to FIM 219.604 per MWh in the Cournot equilibrium, assuming an price elasticity value of 0.6. When the elasticity was assumed to be 0.9, the equilibrium Cournot price was FIM 165.3 per MWh, which is

[42]for example by using a calibration method which endogenises the mark-ups and solving the model as a market equilibrium problem, instead of a planner problem

fairly close to the initial price level. The Cournot equilibrium included only the nine largest generators in the market. When the rest of the generators were included as one competitive fringe firm the resulting Cournot fringe equilibrium price rose slightly less (to FIM 172.2 per MWh) than in the Cournot case without the competitive fringe.

In the case of perfectly competitive market equilibrium the market price turned out to be FIM 98.2 per MWh. Compared to the initial year's level the total electricity generation in the competitive case increased by 19 TWh per year. This reflects the higher load level resulting from a lower price level. The competitive equilibrium improves consumers' welfare, measured by consumer surplus. With a price elasticity value of 0.5 the welfare improvement was roughly equivalent to 5 bn. Finnish marks.

Chapter three extended the single-price single-region model to a three-country two-price region setting. The three countries were Norway, Finland and Sweden, which made up the two price regions: a combined Norwegian-Swedish market and the Finnish market. The division into two price areas was motivated by the fact that Norway and Sweden were running a joint market place, Nordpool, while electricity flows from Finland to Nordpool were subjected to a tariff at the time of electricity market deregulation in Finland and Sweden. The two markets are interconnected by a given transmission capacity which was assumed to amount to15 TWh per year. Subsequently the three countries have been integrated, in that the border tariffs are now abolished.

Several 'policy simulations' were solved. A normal year simulation was implemented by assuming an average annual capacity (about 70% of theoretical maximum) of hydro generation in Norway and Sweden. Compared to the reference year the Cournot price in Finland fell from FIM 160 per MWh to FIM 110.9 per MWh, while the Nordpool price fell from FIM 130 to FIM 79.9 per MWh.

The enlargement of the market place to the Nordic electricity market meant a higher degree of competition which was reflected in the lower Cournot-Nash equilibrium price. The single region model Cournot solution for Finnish market was 219 FIM while the Nordpool model resulted in price of 110 FIM.

Other simulations with the two-region model included the cases of a dominant-firm vs. competitive fringe market and an elastic demand equilibria. In the Cournot-competitive fringe equilibrium the Nordpool price level was higher than in the normal year Cournot simulation, while the Finnish price level remained the same. This reflects the fact that Nordpool is a less concentrated market and the residual demand over which the dominant firms compete is relatively smaller than in Finland.

In the elastic demand case a price elasticity of -1.1 was assumed instead of the -0.6 assumed above. As one would expect the Cournot equilibrium moved towards a competitive outcome as the demand elasticity was increased.

The main focus of Chapters 4 and 5 was on measuring performance (efficiency and productivity) in the Finnish electricity market before and after the market reform. Deregulation and privatisation in general are two policy issues where measurement of productive efficiency have been used extensively to quantify changes that are predicted qualitatively by theory. The main contributions of these chapters are twofold: firstly they represent the first applications of productive and efficiency analysis to the deregulated Finnish electricity sector. Previous studies looked mainly at partial performance measures, such as labour productivity within the sector. Secondly, the final chapters applied sensitivity analysis to a nonparametric data envelopment analysis, especially using bootstrapped confidence intervals for the measured average productivity indices. In Chapter 5, which analysed the performance of the Finnish electricity distribution sector, the data set was also exceptionally extensive by international standards.

Chapter 4 presented an analysis of different measures of technical efficiency and productivity of the Finnish thermal electricity generation. The Data Envelopment Analysis (DEA) method was used. The sample consisted of a plant-specific panel data from the period 1994-1996, with two potential outputs (electricity and heat) and three inputs (labour, fuels and capital) to describe the generation process.

Technical efficiency scores indicated that the generation plants were relatively efficient. In 1994 the average technical efficiency value under the constant returns to scale technology assumption was 0.709, i.e. there was an average need of 29.1 percent reduction of all inputs to reach 100 percent technical efficiency. Under variable returns to scale (VRS) the average technical efficiency score was 0.782 in 1994, a slightly higher value as one would expect. A ratio of the constant returns to scale efficiency score value to variable returns to scale efficiency score value is interpreted as a measure of scale efficiency, i.e.

how close observed output level is to the constant returns to scale level.

Productivity analysis showed that for the 1994-1995 sub-period the average overall Malmquist index value was 1.045, suggesting a growth of 4.5 % in total factor productivity. For the 1995-96 sub-period the growth was even higher, at 7.1 %. The improvement in productivity turned out to be due to improved technical efficiency. The bootstrap technique due to Atkinson and Wilson [11] was applied to the Malmquist average scores to construct the 95 % confidence intervals. It turned out that at the 95 % confidence level the overall Malmquist index average did not display significant productivity improvement during 1994-95, whereas during the 1995-96 period the overall productivity change was significant.

Chapter 5 analysed the technical efficiency and productivity growth of the Finnish electricity distribution sector during the period 1996-1998.

Earlier studies of the Swedish and Norwegian electricity distribution sectors found fairly rapid productivity growth rates. Hjamarsson and Veiderpass [60] found productivity growth in Swedish electricity distribution during 1970-1986 to be fairly rapid; the average annual growth for the 17-year period was 5 %.

In Norway productivity grew by 1.9 % between 1983 and 1989 (Forsund and Kittelsen [42]), while during the period 1994-1995 productivity growth was 5 % (Karlsson [69]). The Finnish productivity growth seems modest by comparison. Total factor productivity fell in 1996-1997 by 1.8 %, and rose by 0.4 % in 1997-1998. In both subperiods efficiency improved slightly. Simulated confidence intervals showed that these changes were not statistically significant (at the 95% level).

A possible reason for the poorer Finnish productivity performance, especially compared to the Norwegian distribution sector, is that energy losses were omitted in this study. When these were included the average improvements were greater, due to some very large falls in delivery loss levels, which were nevertheless considered to reflect the uncertain quality of loss data.

Average technical efficiency under CRS technology was 0.76 in 1996, 0.71 in 1997 and 0.8 in 1998. In Norway it was 0.78 in 1994 and 0.83 in 1995 with a similar model (see Karlsson[69]).

Overall, the conclusion is that in Finland distribution companies were scale efficient and productivity growth was fairly modest during 1996-1998.

In summary, the opening of the Nordic electricity market has improved the efficiency of electricity pricing. For example, in Norway the average yearly price (in real terms - spot market) has fallen by 18-26 percent since 1996 by OECD estimates. As the market structure analysis in this monograph has indicated, the degree of competition within the Nordic market seems to be sufficient. The market power of the largest energy companies may have an impact, especially in times of high load levels, but the market equilibrium price level is still lower than the regulated one.

As for the technical efficiency of the Finnish electricity generation and distribution sectors, the analysis showed that there has been improvement in the productive efficiency and productivity since 1994.

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