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PERFORMANCE BENCHMARKING AND INCENTIVE REGULATION –CONSIDERATIONS OF DIRECTING SIGNALS FOR ELECTRICITY DISTRIBUTION COMPANIES

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ABSTRACT

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Performance benchmarking and incentive regulation – considerations of directing signals for electricity distribution companies

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After the restructuring process of the power supply industry, which for instance in Finland took place in the mid-1990s, free competition was introduced for the production and sale of electricity. Nevertheless, natural monopolies are found to be the most efficient form of production in the transmission and distribution of electricity, and therefore such companies remained franchised monopolies. To prevent the misuse of the monopoly position and to guarantee the rights of the customers, regulation of these monopoly companies is required.

One of the main objectives of the restructuring process has been to increase the cost efficiency of the industry. Simultaneously, demands for the service quality are increasing. Therefore, many regulatory frameworks are being, or have been, reshaped so that companies are provided with stronger incentives for efficiency and quality improvements. Performance benchmarking has in many cases a central role in the practical implementation of such incentive schemes. Economic regulation with performance benchmarking attached to it provides companies with directing signals that tend to affect their investment and maintenance strategies. Since the asset lifetimes in the electricity distribution are typically many decades, investment decisions have far-reaching technical and economic effects.

This doctoral thesis addresses the directing signals of incentive regulation and performance benchmarking in the field of electricity distribution. The theory of efficiency measurement and the most common regulation models are presented. The chief contributions of this work are (1) a new kind of analysis of the regulatory framework, so that the actual directing signals of the regulation and benchmarking for the electricity distribution companies are evaluated, (2) developing the methodology and a software tool for analysing the directing signals of the regulation and benchmarking in the electricity distribution sector, and (3) analysing the real-life regulatory frameworks by the developed methodology and further develop regulation model from the viewpoint of the directing signals. The results of this study have played a key role in the development of the Finnish regulatory model.

Keywords: *electricity distribution, economic regulation, efficiency benchmarking*

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Samuli Honkapuro

- Anyone who stops learning is old, whether at twenty or eighty. Anyone who keeps learning stays young. The greatest thing in life is to keep your mind young. -

Henry Ford

Contents

Nomenclature

Roman letters

A	outage cost parameter for power [€/kW]
B	outage cost parameter for energy [€/kWh]
C	cost
D	loan capital
E	equity
f	weight for peer company
h	efficiency score
I	number of interruptions during a certain time period
J	number of customer groups
K	number of DMUs
m	number of input parameters
n	number of output parameters
p	price
P	price ceiling
$\overline{P}$	average power
R	allowed revenue
R_r	risk-free interest rate
R_m	interest rate in markets
t	interruption time
T	tax expenses
u	weight of output
v	weight of input

X	efficiency factor
x	input
y	output
Z	correction factor for events beyond management control

Greek letters

α	weighting factor
β	beta, describing the risk of the business
γ	weight restricting constant
δ	weight restricting constant
ΔCust	change in the number of customers
η	weight restricting constant
θ	efficiency score
υ	non-negative variable associated with technical inefficiency
λ	weight assigned to peer unit
ν	symmetric error
τ	lifetime of the network
χ	weight restricting constant
ψ	vector of the parameters

Acronyms

AMR	Automatic Meter Reading
AR	Assurance Region
BCC	Banker Charnes Cooper

BCI	Building Cost Index
CA	Number of Customers
CAIDI	Customer Average Interruption Duration Index
CAPEX	Capital expenses
CAPM	Capital Asset Pricing Model
CCR	Charnes Cooper Rhodes
CGA	Customer Growth Adjustment
COLS	Corrected Ordinary Least Squares
CPI	Consumer Price Index
CRS	Constant Returns to Scale
DE	Depreciation Expenses
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DRS	Decreasing Returns to Scale
DSM	Demand Side Management
DSO	Distribution System Operator
EEA	Engineering Econometric Analysis
EMA	Energy Market Authority
ER	Efficiency Requirement
ES	Average Efficiency Score
GER	General Efficiency Requirement
HV	High Voltage
IAER	Individual Annual Efficiency Requirement
IC	Interruption Costs
IER	Individual Efficiency Requirement

IRS	Increasing Returns to Scale
LL	Line Length
LV	Low Voltage
MAIFI	Momentary Average Interruption Frequency Index
MV	Medium Voltage
NDRS	Non-Decreasing Returns to Scale
NIRS	Non-Increasing Returns to Scale
NPAM	Network Performance Assessment Model
NPV	Net Present Value
NV	Network Volume
OHL	Overhead Line
OLS	Ordinary Least Squares
OPEX	Operational expenses
PAM	Preparatory Action Method
PBR	Performance-Based Regulation
PFP	Partial Factor Productivity
PPA	Parametric Programming Analysis
PQ	Power Quality
RB	Rate Base
RC	Reasonable Cost
ROR	Rate of Return
RPI	Retail Price Index
RR	Required Revenue
RRM	Rate-Related Methods
RV	Repurchase Value

SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SDEA	Stochastic Data Envelopment Analysis
SFA	Stochastic Frontier Analysis
SLD	Straight-line depreciation
TE	Technical Efficiency
TFP	Total Factor Productivity
TOTEX	Total Expenses
TR	Tax Rate
UGC	Underground Cable
VRS	Variable Returns to Scale
WACC	Weighted Average Cost of Capital
WTA	Willingness to Accept
WTP	Willingness to Pay

1. Introduction

The restructuring process has changed the nature of the electricity supply business similarly as some other infrastructure industries, such as gas or water supply. Deregulation has opened competition in the generation and sale of electricity, while re-regulation has been introduced in the field of electricity distribution and transmission, where franchised monopolies are considered the most efficient option. Since the formerly self-regulating public utilities have become more or less profit-seeking firms, which are operating in the monopoly position, economic regulation is needed to guarantee customer rights and to prevent the misuse of the monopoly position.

However, while the needs for economic regulation are well grounded, the consequences of regulation for the companies and the whole industry, as well as for an individual customer and the entire society are still somewhat unclear. It is unavoidable that economic regulation directs companies in their everyday operational activities and long-term strategic planning. Nevertheless, these directing signals are in many cases blurred, and furthermore, too little attention has been paid to the analysis of these signals in the development of regulatory models. Especially in such an industry as electricity distribution, where the asset lifetimes are typically long, usually many decades, investment decisions have wide-ranging impacts. Therefore, misleading directing signals of economic regulation may cause significant costs for society in the long term.

1.1. Electricity distribution business

Electricity distribution plays a significant role in the electricity supply chain; in particular, when considering from the customer's perspective. In Finland, for instance, about a quarter of the price of electricity for a household customer comes from electricity distribution, as can be seen in Fig. 1.1. In addition, over 90 per cent of the customers' interruptions are caused by faults in the distribution network (see e.g. ET 2007).

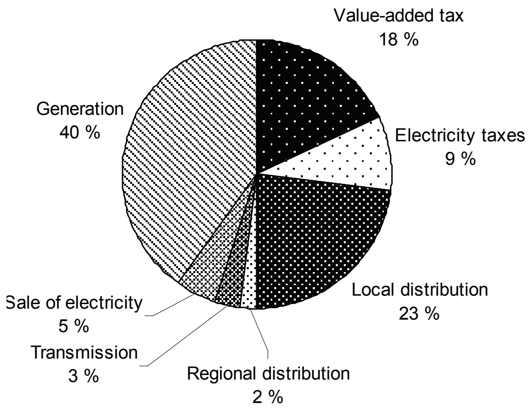

Figure 1.1. Distribution of the price of electricity for an electrically heated household in Finland (EMA 2007b).

The costs of electricity distribution can be categorised into operational and capital costs; these are usually called OPEX (operational expenses) and CAPEX (capital expenses). Further, operational costs can be divided into those that can be controlled by the company and into non-controllable cost items. Controllable operational costs consist of the operation and maintenance of the network, electrical losses, administrative costs, customer services, and corporate overhead costs. These include cost items such as material and energy purchases, staff costs, rents and external services, as well as overhead costs. Non-controllable costs are beyond the company's control, and they consist mainly of transmission fees. Capital cost, on the other hand, consists of depreciations and the financing cost of the loan capital or return on equity. The typical cost structure of a Finnish electricity distribution company is illustrated in Fig 1.2.

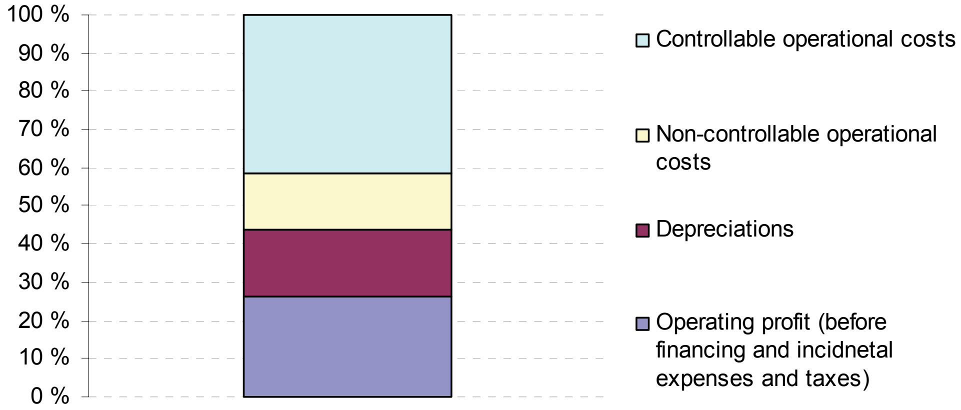

Figure 1.2. Typical cost structure of a Finnish electricity distribution company (EMA 2007d).

The quality of power distribution can be divided into the quality of customer services, reliability and voltage quality, as shown in Fig 1.3.

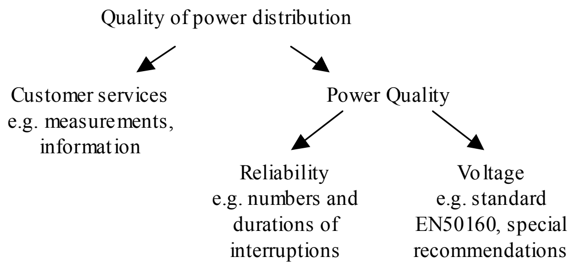

Figure 1.3. Quality of power distribution (Partanen et al. 2005b).

Reliability refers to interruptions in the power supply, as for instance Rivier and Gómez (2000) have illustrated. Interruptions can be divided into those, which are announced in advance to the customers, and into unannounced ones. The latter are caused by faults, while announced ones are usually associated with maintenance works. In addition, interruptions can be divided into long interruptions and short interruptions, latter of these last less than three minutes and they are usually cleared by automated switching sequences. Voltage quality, instead, is related to the characteristics of the voltage wave, that is, issues such as the variation of frequency and voltage level. The quality of the commercial services includes issues such as metering and billing.

However, the terminology concerning the quality of power distribution is somewhat unstable; for instance, voltage quality is sometimes also called power quality; see for example Ajodhia and Hakvoort (2005). In this thesis, quality related terms are defined as follows: the term *power quality* refers to both reliability and voltage quality; the term *quality of supply* refers to reliability; and the term *service quality* refers to the whole quality of power distribution. However, economic regulation focuses usually solely on the quality of supply, and hence this work concentrates mainly on that part of the service quality. Therefore, when discussing about the power quality the major focus is on the quality of supply.

The quality of supply can be improved by both operational activities and network investments. Table 1.1. presents the methods that are generally applied to decrease the number and duration of interruptions.

Table 1.1. Impacts of investments and operational activities on reliability and operational costs (↘ = decrease, ↗ = increase) (Honkapuro et al. 2005, Lassila et al. 2005a).

	Customer level impacts			
	Long interruptions			
	Number	Duration	Short interruptions	OPEX
Network topology				
New primary substations	↘↘	↘	↘	↘
New MV lines (to short line length / breaker)	↘	↘	↘	↗
Back-up lines	↘	↘↘	-	↗
Network components				
Replacing overhead lines with underground or coated cables	↘↘	-	↘↘	↘↘
Surge arresters	-	-	↘↘	-
Earth fault current compensation	↘	-	↘↘	-
Network automation				
Remote-controlled disconnectors	-	↘↘	-	↘
Fault location system	-	↘↘	-	↘
Operation and maintenance				
Forestry work	↘	-	↘↘	↗
Network building and maintenance under operation (voltage works)	↘↘	↘↘	-	↗

Investments in the electricity distribution can be divided into extension investments and replacement investments. For instance, building a new medium-voltage feeder is an extension investment, while renewing the poles of an existing feeder is a replacement investment. Generally, the basic difference of these investment types is that an extension investment increases the repurchase value of the network, while replacement investments affect only the present value of the network.

The business environment of the industry has undergone some major changes during the past few decades: formerly, electricity distribution was a part of vertical integrated business, where the generation, distribution and sale of electricity were bundled together in the same utility. After the restructuring process, which in Finland took place in the 1990s, the generation and sale of electricity were opened up to competition. However, in electricity transmission and distribution, free competition is rarely seen as the best option, when considering from the economic or technical point of view. For instance Filippini (1998) concludes, based on empirical studies, that franchised monopolies, instead of side-by-side competition, are the most efficient form of production in the electricity distribution industry. Similarly, Ramos-Real (2005) states, based on the analysis of earlier cost function studies, that transmission and distribution grids are natural monopolies, and duplicating them does not make sense. In addition, Gunn and Sharp (1999), based on the analysis of New Zealand's distribution business, indicate that distributors are most probably in the position of sustainable natural monopolies. Nelson and Primeaux (1988) instead suggest that competition may be a viable option in the transmission and distribution of electricity. However, this study was based on the data from the period of 1961–1976, and, as the authors admit, there have been many changes in the industry after that time period. Based on these findings, we may conclude that the transmission and distribution of electricity can be considered natural monopolies; thereby, they usually operate as franchised monopolies after the restructuring process. Hence, the typical structure of the power supply sector after restructuring is illustrated in Fig. 1.4.

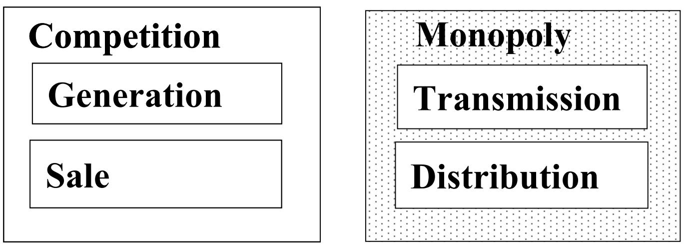

Figure 1.4. Typical structure of the power supply sector after restructuring process, Viljainen (2005, p. 2).

However, technological development may have effects on the sustainability of natural monopolies; for instance, Künneke (1999) lists technological development steps, such as decentralised production of electricity, controllability of electricity transport, and multifunctionality of the networks as possible trends that may affect the natural monopoly characteristics of electricity distribution. In addition, Hakvoort (2000) sees more efficient grid management and the miniaturisation of generation systems as possible sources of changes in the nature of the industry. Based on these, it can be concluded that there may be technological advances in the future that may have an effect on the sustainability of the natural monopoly, and regulation and political decision-making should stimulate rather than hinder technical development of this kind. Furthermore, there are currently some small exceptions in the legal monopoly of the distribution companies. For instance, according to the Finnish Electricity Market Act (386/1995), a third party is entitled to construct a service line within a distribution system operator's (DSO) area, which connects an electricity user or generation to the network. In the case of generation of electricity, it can also be connected to a network other than the DSO's own one.

However, even if electricity distribution is defined as a natural monopoly, it can be questioned whether all the operations of the electricity distribution should be included in the franchised monopoly. Viljainen (2005, p. 29) has suggested that the size of the regulated monopolies could be reduced by limiting the status of the natural monopoly to the ownership of the networks, and introducing competition to other activities. For instance, according to Ramos-Real (2005), metering and billing are activities that do not have natural monopoly characteristics. Furthermore, regulated tasks of the DSOs vary between the countries to some extent. For instance, Norwegian distributors are required to attend to some tasks, such as preparing of the energy forecasts for service area, which are not included in the tasks of the DSOs in other Nordic countries, as illustrated in Nemesys (2005c). Reducing the size of the natural monopoly could lead to efficiency improvements in the operations that are under competition, if the markets in such services are well functioning. However, this kind of restructuring does not eliminate the need for economic regulation in some parts of electricity distribution.

When considering the nature of electricity distribution, some special characteristics of the business are highly relevant, especially in view of economic regulation. First, society is nowadays highly dependent on electricity, and then again, large-scale storing of electrical energy is difficult and expensive. Therefore, uninterrupted power supply is vital to society. Secondly, the role of electricity distribution is something between a public service and private business, and also the ownership of the companies is divided between the public owners, that is, municipalities or state, and private owners. Different owners have different objectives; there are some companies that are seeking the maximum profit, while others are focusing on providing the public infrastructure services with low profits. However, the strategy of a company, that is, whether it is striving for high profits or not, does not necessarily depend on the ownership; also public-owned utilities may have a strategy that aims at high profits[1]. Thirdly, the asset lifetimes are long, usually several decades, in the electricity distribution. Hence, investment decisions have long-lasting effects in the distribution network. Further, in many cases, electricity distribution networks are constructed on terms of the development of society, and thus the utilities themselves have not total control on when or where networks are built. All these issues have to be taken into account when developing a regulatory model for the electricity distribution industry.

1.2. Regulation of monopoly business

When discussing regulation, the role of the two different types of regulation have to be defined. These are technical regulation and economic regulation. The first of these two defines the technical rules for the building and operation of the power system. Hence, it includes for instance safety guidelines and voltage limits. However, this thesis focuses on economic regulation. The primary aim of economic regulation is to prevent the misuse of the monopoly position by ensuring that companies do not overcharge their customers and that the service quality is at an adequate level. In addition, the regulator has a task to balance the rather controversial expectations of all the interest groups, viz. customers, society, asset owners, and distribution companies. Customers mainly expect reasonable pricing of electricity and a sufficient level of the quality of supply. The interest of society is closely related to the interest of the customers, but society has also some expectations on the development of the essential infrastructure network. Asset owners expect a reasonable return on invested capital, while it is in the interest of the distribution company that the business environment remains stable and that the company is entitled to gather revenue that is sufficient to operate and develop the

[1] For instance, in Finland the profits of the municipally owned companies have been relatively high in many cases (see for instance Talouselämä 2007).

distribution network. Expectations of the stakeholders in Nordic countries have been analysed by surveys and interviews during the project concerning the pan-Nordic regulation model (Nemeys 2005a). In those analyses, it has been found that the need for regulation is accepted by all the stakeholder groups, and it is seen important that the regulation focuses on long-term issues. It is obvious that the customers and the government put more emphasis on low tariffs than the DSOs and the investors. However, it has been found that stability is important for all the stakeholders, and for instance stable tariffs are generally more important than low tariffs. In addition, quality issues were seen generally as important as economic issues; only investors put more emphasis on economic than quality issues.

One of the main problems in the economic regulation is the asymmetry of information between the regulator and companies. This is typically defined as a principal-agent problem, where the objectives of the principal and agent diverge, and the principal tries to find an optimal incentive scheme for the agent, without full information about the circumstances and behaviour of the agent, as presented by Vickers and Yarrow (1988, pp. 7–9). This theory can be applied in the regulatory analysis, where the regulator is the principal and regulated company is the agent. The regulator is willing to direct the company to plan its pricing, outputs, and investments to fulfil the interests of the public, but the company is mainly interested in maximising its profits; further, it has the monopoly of the information about the cost conditions, for instance, as Vickers and Yarrow (1988, p. 92) have shown. In the regulatory development, the objective is to find an appropriate regulation framework, given the information available, which directs companies to perform the required operations by a most efficient way, without leading to bankruptcy or excessive profits. An unobservable issue may be the costs structure or the extent of the cost-reduction efforts of the company as Vickers and Yarrow (1988, p. 99) have shown.

The needs to direct companies to build and operate their networks in the most efficient manner is a key issue in the economic regulation, because of the absence of the efficiency incentives in the monopoly business. When a privatisation process is going through a formerly public sector, such as electricity distribution, it is assumed that there will be at least some efficiency gains. In other words, private companies are expected to increase the cost efficiency of the industry after taking over the public sector's duties. Efficiency improvements are also included in the expectations of the European Parliament. It is stated in the Directive concerning internal markets in electricity (96/92/EC) that the establishment of the internal market in electricity is of particular importance in increasing the efficiency of the industry. Furthermore, in the Directive concerning common rules for the internal market in electricity (2003/54/EC), it is clarified that the implementation of the earlier directive shows the benefits, including efficiency gains and price reductions. Therefore, providing efficiency incentives for the companies is among the essential objectives of the economic regulation.

1.2.1. Regulation models

Economic regulation in electricity distribution sector is usually focused either on the prices of electricity or on the profits of a company, and regulatory decisions can be made before or after the regulatory period, that is, the regulation can be *ex-ante* or *ex-post* by nature. Typically, a division between the *bottom-up* and *top-down* regulation is made, where profit regulation belongs to the first of these and price regulation to the latter one. Often, top-down regulation is applied in ex-ante regulation, and bottom-up in ex-post, as shown by Kinnunen (2006). In addition, Viljainen (2005, pp. 15–16) has demonstrated that it is a common approach in practice to apply ex-post profit regulation in the early stages of the economic regulation, and to use more developed schemes, such as ex-ante price regulation, in more mature regulatory environments. However, this does not mean that the price regulation should always be ex-ante and profit regulation ex-post, but this is a commonly applied practice. Only the basic ideas of the regulation models are given in this chapter; a more detailed analysis of the models will be presented in the latter parts of the thesis, see for instance section 3.1.

1.2.1.1. Profit regulation

The basic idea of *profit regulation* is that the regulator determines the maximum allowed rate of return, and companies are allowed to collect the revenue that is adequate to cater this return on capital, as well as their typical operational and depreciation expenses. Such a regulatory scheme is often referred to as *cost-recovery regime* (see for instance Nemesys 2005b).

1.2.1.2. Price regulation

Price regulation can be carried out by regulating either directly the prices of the services or the total revenues of the regulated firms. The former approach is called *price cap* and the latter *revenue cap regulation*. A usual approach is to set the limit such that annual prices or revenues are not allowed to increase more than the retail price index (RPI) minus the efficiency factor X. Therefore, the method is usually referred to as RPI-X regulation, but sometimes also the term CPI (Consumer Price Index) is used instead of the RPI.

1.2.1.3. Other regulation models

In addition to price and profit regulation, there are some other solutions for regulation of the monopoly companies. In *yardstick regulation*, the regulated companies are compared against each other, and the allowed incomes are based on the performance of the company, as shown by Jamasb and Pollit (2000). Closely related to yardstick regulation is to benchmark companies against a hypothetical efficient company, as demonstrated by Vogelsang (2002). Furthermore, in *profit sharing regulation*, customers participate in excess profits or profit shortfalls of the utility by ex post refunds or price reductions, as Vogelsang (2002) has shown. In addition, regulator can offer the *menu* of incentive schemes for companies, and a company can choose the best fitting one, as Jamasb and Pollitt (2000) have demonstrated. One solution for the regulatory problem is also to award the delivery rights and obligations based on *auctions* among the qualified bidders, as shown in Nemesys (2005b).

1.2.2. Performance studies in economic regulation

The incentives for efficiency gains for monopoly companies have to be provided by the means of economic regulation, and consequently, the goal of regulation is to be a substitute for competition, as stated by Olson and Richards (2003). According to Coelli et al. (2003, p. 6), the regulator has three efficiency-related obligations: the regulator must ensure that the costs of delivering the services are minimised, the prices charged for activities reflect their costs, and finally, the regulated industry sector grows appropriately. To fulfil these objectives, the measurement of the efficiency is in many cases included as a part of the regulatory framework.

Measurement of the efficiency is usually called *efficiency benchmarking*, or sometimes just *benchmarking*. The term benchmarking is widely used both in common speech and in the economic literature, and may have slightly different meanings in different contexts. In this thesis, the term benchmarking can be defined, as presented by Jamasb and Pollitt (2001), as “the comparison of some measure of actual performance against a reference or benchmark performance”. In this work, the term *regulatory benchmarking* stands for the benchmarking that is used in the regulatory calculations.

Benchmarking can be utilised to compare the performance of multiple companies in a certain observation time, or the approach may be to compare the performance of the companies between different time periods. In addition, the role of the benchmarking is dependent on the applied regulation model. In RPI-X style regulation, annual efficiency requirements, that is, the X-factor, are set for the regulated companies. These can be divided into a general efficiency requirement and a company-specific requirement, and they can be focused either on individual cost components or on the prices or the total revenue of the company. The general efficiency requirement reflects the presumption of the productivity growth in the industry, while the company-specific requirement is based on the evaluation of the company’s individual efficiency potential compared with other companies. Both of these indices can be produced by the performance measurement; the individual efficiency requirement is usually based on the efficiency differences of the companies, while the general efficiency requirement can be derived from the discovered yearly change of the efficient frontier. Hence, the role of the benchmarking in such a regulatory scheme is to provide information about the perceived and expected productivity growth of the companies. In the yardstick regulation, the allowed incomes of the companies are based more directly on the performance differences between the companies. Consequently, the main role of the benchmarking in such a regulatory regime is to introduce competition between the monopoly companies.

1.2.3. Directing signals of regulation

When considering the directing signals of regulation, the relevant questions are: (1) what are the regulated subjects, (2) which subjects are excluded from regulatory calculations, and (3) how can a regulated company affect these subjects. In other words: what is the focus of the regulation and how do the regulated companies generally operate to fulfil the demands of the regulator. This is a key issue in principal-agent –problem, which has been discussed above.

In electricity distribution, similarly as in many other regulated industries, regulation focuses on the price or profit, as it is stated above. However, to find out the directing signals, the regulatory model obviously has to be defined in more detail. Relevant issues are, in particular, the cost components and quality indices supervised by the regulator, but also the subjects that are not included in the regulation, such as pass-through cost items. For instance, the role of the operational and capital costs may be different, which obviously affects the directing signals of the regulation.

However, although regulation provides companies with guidelines for adjusting their cost and quality levels, the actual effects can be seen in the network investments and operational activities of the companies. Hence, to find out the directing signals of the regulatory framework, the economic effects of typical development actions of the distribution company have to be analysed. This way, it can be determined whether the regulation model provides companies with incentives for quality improvements, or if the companies gain higher profits by neglecting the network investments, for instance.

It is relevant to separate the directing signals of the technical and economic regulation. Technical regulation contains specifications on the technical issues of the distribution networks, for example limits for voltage levels. Thereby it provides clear directing signals for the planning of the distribution network, for instance. A real-life example of the directing signals of technical regulation is the 1 kV low-voltage network. According to Partanen et al. (2005a), the EU low-voltage directive enables the use of the 1 kV low-voltage level in the distribution network; further, the use of the three-voltage-level (20/1/0.4 kV) distribution system has proven to be an economical solution to improve the reliability of rural area distribution networks. Consequently, it can be said that technical regulation has created directing signals that have triggered off the development of the new principle for distribution system planning.

While the limits and instructions of technical regulation are unambiguous, economic regulation can contain requirements that are either dependent on the performance of the company or that can be fulfilled by different actions. For example, if a company is required to decrease its revenues, it can either decrease costs or shrink profits, and the cost savings can be achieved by different actions. In addition, metered issues are more accurate in technical regulation than in economic regulation; for example, voltage is a more unambiguous quantity to measure than efficiency. Hence, the directing signals of economic regulation may not be as straightforward as they are in the case of technical regulation.

The directing signals of a certain supervision system can generally be divided into effects that enable or disable some issues or actions. As the previous example, concerning the technical regulation, shows, there is an enabling effect in the technical regulation, which launches the development process of a new technical solution. However, the division of directing signals is not always limited only to the enabling and disabling ones, but there can also be signals that either encourage or discourage some action, in other words, these are strengthening or weakening signals. Signals of these kinds are typical for economic regulation. For instance, depending on the regulation model, there can be either positive or negative incentives for replacing overhead lines with underground cables; however, cabling is seldom strictly forced or disabled by economic regulation. In addition, directing signals can be intended or unintended. For instance, one aim of the regulation is to direct companies to operate their network in the cost-efficient manner, and design their network investment so that total socio-economical welfare is maximised. Hence, these are the intended directing signals of the regulation. However, regulatory framework may also provide unintended directing signals, for instance companies may be encouraged to maximise the transferred energy, which is against energy efficiency objectives.

The directing signals of the economic regulation have usually been studied theoretically by analysing the principal-agent problem. Bogetoft (1994, 1995, 1997, 2000) has analysed the productivity measurements from the incentive provision point of view. He has studied the behaviour of the agents, that is, the opportunistic DMUs (Decision Making Units), under certain productivity measurements. The key issue in those studies is the evaluation of the production plan, which the agent will implement, when there is a certain contract between the principal and the agent. The aim of such studies is to find how the agent can be motivated to appropriate behaviour by the most efficient way. These analyses are applied in the regulation of electricity distribution by Agrell et al. (2000). Furthermore, similar analyses concerning the steering mechanisms of the quality regulation in electricity distribution are made in Nemesys (2005b). In addition, Burns et al. (1998) have analysed the behaviour of a company under regulatory constraints. However, the viewpoint of these studies is chiefly theoretical and less attention is paid to practical cases.

A more practical analysis about the behaviour of the distribution companies under the regulatory constraints have been made by Jamasb et al. (2003, 2004). They have found that companies under regulatory benchmarking may pursue virtual efficiency improvements to increase their profits without true efficiency gains by gaming. Grenard and Strbac (2003) have also analysed the effects of the regulation to the investments of the distribution companies by studying incentives that the regulation model used in the UK gives for minimising the life cycle costs. The special focus of this study was on the regulatory incentives for reducing electrical losses. These incentives were found to be too weak in the UK model. Kinnunen (2006) has studied investment incentives in the previous Finnish regulation model, finding that the influence of the rate of return regulation to the investments is only weak. On the other hand, she has found that the liberalised markets have influenced the investment behaviour by increasing uncertainty. However, the main focus of her study has been in the effects of the ROR regulation, and not in the efficiency benchmarking. The efficiency benchmarking of the Finnish electricity distribution sector from a methodological point of view has been considered in detail by Korhonen and Syrjänen (2003). However, their studies concentrate mainly on the analysis and development of the benchmarking methodology, their main focus having not been on the practical directing signals.

1.3. Objectives of the study

To summarize the previous sections, we may state that economic regulation is a necessary element in the restructured power supply sector. In addition, there are directing signals, either intended or unintended, which direct companies in their operations. Because of long asset lifetimes and a high capital intensity in the industry, these directing signals may lead to large and long-lasting economic impacts. Hence, a poorly designed regulation model may lead to significant indirect costs, as stated by Viljainen (2005, p. 8). In practice, such indirect costs may occur during a long time period for instance owing to the overinvestments, which may be encouraged by the regulatory framework. Therefore, it is essential to find out the practical directing signals of the economic regulation and take these signals into account during the development process of the regulatory framework. Hence, it has to be found out what kinds of directing signals does the regulation provide for companies, and what are the generating mechanisms of these signals. In this thesis, the term generating mechanism refers to an issue that creates a directing signal, either unintentionally or on purpose. Such an action may be, for instance, including an input parameter in efficiency benchmarking, or choosing the benchmarking methodology.

The directing signals of the incentive regulation have been mainly studied in economic literature by analysing the behaviour of the agent under the principal-agent arrangement and considering the regulated company as an agent and the regulator as a principal. However, these studies are usually characterised by a highly theoretical viewpoint, and they seldom include an industry-specific perspective. If the actual directing signals have to be found, the characteristics of the industry have to be taken into account. Since the development of regulation is in many cases piecemeal, the analysis of the directing signals during the development process may be limited only to the developed part of the model. In such a situation, the directing signals of the whole regulatory framework may not be found. In order to analyse the practical directing signals that the efficiency benchmarking and economic regulation provide for electricity distribution companies, the effects of the whole regulatory framework have to be taken into account. In practice, this means that all the effects that the input data have on the allowed incomes of the companies are analysed. In the electricity distribution business, such a comprehensive analysis of the directing signals of the regulatory framework has not been made before. Therefore, it can be said that there are clear needs for such an analysis in the electricity distribution sector.

This thesis concentrates on the analysis of the directing signals of the performance benchmarking and incentive regulation in the electricity distribution sector. The incentives for network investments and quality improvements are studied. The objectives of the thesis are:

1) To find out the generating mechanisms of the directing signals that efficiency benchmarking, as a part of the incentive regulation, creates for electricity distribution companies. The research methodology applied in this part is theoretical analysis.

2) To create an industry-specific methodology for analysing the directing signals of the regulatory benchmarking of the electricity distribution companies, and to apply this methodology in practice by developing a special software tool.

3) To implement the above-mentioned tool and methodology in practice by analysing and developing the regulatory framework from the directing signals point of view. The research approach in this part is heuristic, and the research is characterised as a case study.

In addition, the directing signals found in the study are compared with the real-life effects of the regulation. This is done by a case study, where the effects of the former Finnish regulatory framework on the price and quality of the electricity supply, as well as the cost and investment levels of the Finnish distribution companies, are analysed.

Because the focus of this thesis is on the analysis of the directing signals, actual methodological development of the benchmarking models has not been considered. That is, mathematical benchmarking models have been taken as they are, whereas the selection of the benchmarking parameters, methodological choices such as returns-to-scale assumptions, and the implementation of the results are considered in detail in this work. In addition, the Data Envelopment Analysis (DEA) has been taken as the basis of the closer analysis, as it is a widely spread model that is or has been used for regulatory purposes in many countries (see for instance Jamasb and Pollitt 2001), and also because the development of the regulatory usage of the DEA has been going on for several years in Finland. The objective of this thesis has not been to find the best benchmarking model, but to analyse the directing signals of the implementation of benchmarking in economic regulation. However, many of the outcomes of this thesis do not depend on the benchmarking method itself. Although the main focus of the thesis has been in the electricity distribution sector, many of the outcomes of this work may be analogous to other infrastructure industries, such as water or gas supply. Nevertheless, the applicability of the results to other industries has not been considered in detail. The analyses in this thesis are mostly based on the Finnish regulatory model. Hence, the main approach has been to analyse the model, in which the role of the benchmarking is to produce an efficiency requirement for the regulated companies, that is, the X-factor in the RPI-X style regulation.

1.4. Outline of the thesis

This doctoral thesis is based on the outcomes of the research projects that have been carried out at Lappeenranta University of Technology during the past five years. The research projects have been done in close co-operation with the Energy Market Authority and the electricity distribution industry. In addition, many of these research projects have been carried out in collaboration with Tampere University of Technology. The most relevant research projects for this thesis have been: *Development of the benchmarking method of the electricity distribution business* (Lassila et al. 2003b)*, The role of power quality in the regulation of electricity distribution business* (Järventausta et al. 2003)*, Investments in regulation – especially in efficiency benchmarking* (Partanen et al. 2004)*,* and *Further development of the efficiency measurement model based on the DEA method* (Honkapuro et al. 2006c).

All of these projects have been related to a larger research topic, economic regulation in the electricity distribution industry. The projects have been carried out within a research group, and the major role of the author in these research projects have been the analysis of the directing signals of the efficiency benchmarking. In other words, the research results presented in this thesis are those outcomes from these projects, which the author himself has produced. The author has presented some of the key findings of this thesis in his earlier works (see for instance Honkapuro et al. 2004a; Honkapuro et al. 2005; Honkapuro and Partanen 2006; Honkapuro et al. 2006a; Honkapuro et al. 2006b; Honkapuro et al. 2007). These works have been published in conference proceedings and presented in international conferences, and have thereby been exposed to the criticism of the scientific community.

The outline of this thesis is following. The theory of performance benchmarking is presented in Chapter 2. The implementation of incentive schemes in economic regulation is discussed in Chapter 3, which presents the theory of the regulation models and considerations about the role of the quality of supply and efficiency benchmarking in economic regulation. Chapters 2 and 3 provide the theoretical background for the research and discuss the first objective of the thesis, the evaluation of the generating mechanisms of the directing signals of the performance benchmarking and incentive regulation. Chapter 4 concentrates on the former methodology of economic regulation in the Finnish electricity distribution sector and its impacts. The chapter provides thus a case study about the real-life effects of the regulation and describes the former Finnish regulatory framework, which was a starting point for the regulatory development, illustrated in the latter part of the thesis. Chapter 5 addresses the second and third objectives of the thesis by presenting the methodology and tool for the regulatory development and by describing their practical implementation in the development of the Finnish regulatory benchmarking. The third objective of the thesis, the analysis and development of the regulatory framework, is discussed further in Chapter 6, where the new Finnish regulatory model and its directing signals are presented. Conclusions are made in Chapter 7.

2. Theory of efficiency benchmarking

Striving for efficiency gains has been one of the driving forces in the restructuring process in the electricity supply industry. Thus, the measurement of efficiency is in an essential role in this process; the efficiency potential of the companies has to be measured in order to set the efficiency targets. On the other hand, efficiency benchmarking is a useful tool for determining the reached efficiency gains. In addition to these, efficiency benchmarking can be used to mitigate the problem of the asymmetry of information between the regulator and the company. In practice, the measurement of efficiency is based on the comparison of the performance of the units; therefore, also the term *performance measurement* instead of efficiency measurement is used in some cases.

In this chapter, the performance measurement process is illustrated. First, the concept of efficiency is discussed; this includes definition of the basic terminology associated with efficiency and productivity, which is a common source of confusion in many cases. The chapter also includes considerations on efficiency itself: what is efficiency and how it can be measured. After that, the efficiency measurement methodology will be addressed, including the basic principles of efficiency measurement and the description of some popular benchmarking methods, as well as some considerations on parameter selection. This chapter provides the theoretical background for the study and discusses the first objective of the thesis, the evaluation of the mechanisms behind the directing signals of the regulatory benchmarking.

2.1. Concept of efficiency

Efficiency is usually defined as the performance of a unit compared with optimal performance. If we consider the efficiency of a company, it is usually measured as *productive efficiency*. The productivity of a unit is defined as the ability of the unit to produce one or more outputs by using one or more inputs, as shown in Equation (2.1)

$$Productivity = \frac{Outputs}{Inputs}. \tag{2.1}$$

Hence, the efficiency of a company can be measured as the unit's productivity compared with the maximum productivity. If all the inputs and outputs are involved in the productivity measurement, it is called *total factor productivity*, as presented in Coelli et al. (2005, p. 3). However, if only a part of the factors is included, the term *partial factor productivity* is used. Maximum productivity can be defined as a theoretical function specified by engineering analysis, or it can be based on the best practices observed from the data set, as demonstrated by Farrell (1957).

If we look at efficiency, we find that efficiency can be measured as *technical efficiency*, *allocative efficiency*, *scale efficiency* or *cost efficiency*. The following illustrations of the definitions of the efficiency terminology are based on the definitions of Farrell (1957) and Coelli et al. (2005). Let us consider a situation, where a unit A produces one output (y) by utilising two inputs (x1 and x2). The unit A and some relevant information for the efficiency measurement are sketched in Fig. 2.1. In this case, it is assumed that the amount of output production is constant and it is equal for every unit of this example.

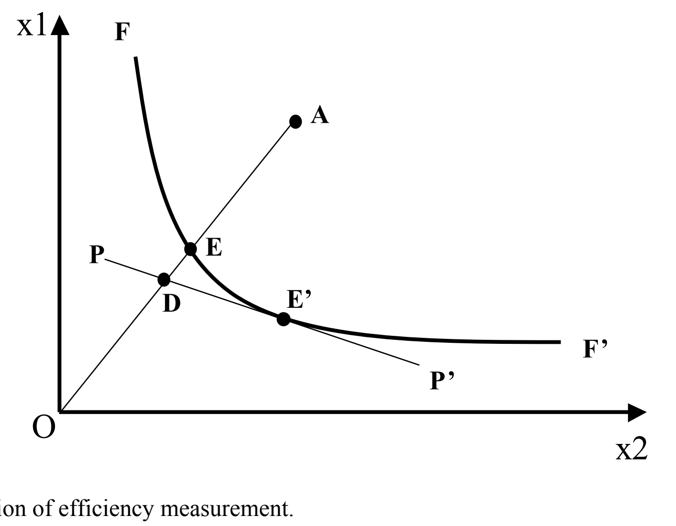

Figure 2.1. Illustration of efficiency measurement.

The curve FF' in Fig. 2.1 represents the combinations of the input factors that an efficient unit can use to produce a certain amount of the output. If we look at the unit A, we can see that it uses both the inputs for more than the efficient amount, described by the isoquant FF'. Thus, we can say that the unit A is not efficient, and in order to be efficient, it should use the inputs for the same amount as the efficient unit E. Hence, the technical efficiency of the unit A can be determined as a ratio of efficient inputs to actual inputs, in this case OE/OA, which on the other hand reflects the *radial* distance of the unit to the efficient frontier. However, a unit is defined as efficient, if it lies on the efficient frontier. Hence, efficiency may be determined also by *non-radial* efficiency measurement, for instance, by looking the shortest distance to the efficient frontier, as Coelli et al. (2005, p. 57) have shown. However, radial measurement is a usual approach in the efficiency evaluations.

However, even if the unit E, lying in the efficient frontier, is technically efficient, in other words, it is using an efficient amount of two inputs to produce an efficient amount of the output, it might still be able to reduce its costs by choosing a more efficient mix of two inputs. Hence, it is possible that company is found as technically efficient, but its input and output mix may be far from optimal. In Fig. 2.1., the slope of the line PP' represents the ratio of the prices of two input factors. Thus, it can be said that E' is the optimal mix of the inputs and thereby a more efficient production point than E. Consequently, the *price efficiency* of the unit E can be determined as the ratio of the OD/OE. In many cases (see for instance Coelli et al. 2003), the term *input mix allocative efficiency* is used instead of the term price efficiency. If we have a multiple-output case, the *output mix allocative efficiency* can be determined accordingly. However, to determine the price efficiency, information about the prices or values of the inputs and outputs is obviously needed. The product of the technical efficiency and price efficiency, that is for the unit A the ratio of the OD/OA, reflects the *overall efficiency* of the unit. The term *cost efficiency* is also used, for instance in Coelli et al. (2003). As long as the efficient frontier, in this illustration the line FF', is determined such that none of the units lies between the efficient frontier and origin, the efficiency scores will vary between 0 and 1, where the value 1 represents the efficient value.

2.1.1. Scale efficiency

If the proportional increase in the inputs is thought to lead to an equivalent increase in the outputs for every unit, it is said that there is a *constant return to scale* (CRS). However, in many cases, it is assumed that the productivity of the unit varies by the scale of the operation, and therefore a *variable returns to scale* (VRS) supposition is used. If the increase in the outputs is faster than the increase in the inputs, it is said that there are *increasing returns to scale* (IRS). On the other hand, when the increase in the outputs is slower than the increase in the inputs, there prevail *decreasing returns to scale* (DRS). In many cases, see for instance Cooper et al. (2002), increasing returns to scale are referred as non-decreasing returns to scale (NDRS), and similarly, the term non-increasing returns to scale (NIRS) is used instead of the decreasing returns to scale. The usual approach is to presume that the returns to scale change as the scale of operation varies so that the production function forms the shape of the s-curve, as shown in Fig. 2.2.

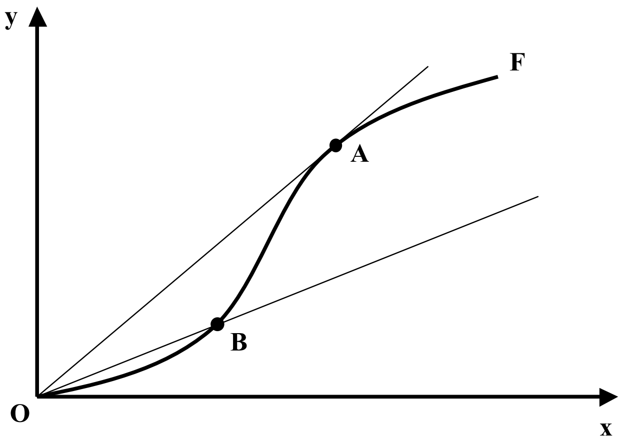

Figure 2.2. Illustration of the production function in one input (x) one output (y) case.

In Fig. 2.2., there is one input (x) and one output (y). The curve OF is the production function, representing the technically efficient productivity. The same figure shows two units, A and B; as we can see, they lie on the curve OF, which means that they are both technically efficient. However, if we consider the productivity of these two units, which is measured as an outputs per inputs ratio, we discover that the productivity of the unit A is higher than that of the unit B. Actually, since productivity is the ratio of outputs to inputs, in this case it can be measured as the slope of the line that is drawn through the origin and the data point, so that a steeper line represents a higher productivity. Since A and B are both technically efficient, but the productivity of A is higher than that of B, we may conclude that A is operating at a more optimal scale than B, or to put it in other terms, A has a higher *scale efficiency* than B. In Fig. 2.2., the point A represents the most efficient unit, since the line drawn through the origin and the point A is the steepest that can be drawn through the origin and the production function. Thereby the line AO represents the efficient production function, which is the efficient frontier in the constant returns to scale case. Therefore, the technical efficiency of the unit B in the constant return to scale case can be measure based on the distance of the unit to the efficient frontier, in this case the line AO. The scale efficiency of the unit, again, can be defined by the ratio of the constant return to scale technical efficiency to the variable return to scale technical efficiency.

2.1.2. Input or output orientation

In efficiency measurement, it should be defined whether the measurement is input or output oriented. In input-oriented efficiency measurement, it is assumed that the efficiency improvements are achieved by decreasing the input usage, and the outputs are outside of the company's control. Hence, in the input-oriented model, the efficiency score smaller than one specifies the amount of the inputs company can use to achieve the efficiency with the current level of outputs. For example, if the efficiency score is 0.8, the company can use 80 % of its inputs in order to be efficient. In the output-oriented model instead, it is assumed that companies improve their efficiencies by increasing the amount of the outputs they produce. Thus, an output-oriented efficiency score indicates the amount by which the produced outputs should be increased, when the level of inputs is constant.

In electricity distribution, the outputs are usually those that are mainly outside the company's control, for instance energy delivered to the customers (the inputs and outputs of the electricity distribution are discussed in more detail in section 3.2.). Therefore, input orientation is a common approach in this industry; see for instance Coelli et al. (2003, p. 15).

2.2. Benchmarking methods

In the previous section, the fundaments of measuring the efficiencies were discussed. As explicated, the basic idea is to compare the ratio of the outputs over inputs of the observed unit to the efficient value. Therefore, issues such as defining the efficient frontier, and determining the prices of the inputs and outputs, have to be solved during the practical measurement of the efficiency. The efficient frontier is usually determined based on the actual performance of the companies, but in some cases it can also be based on some theoretical optimum. Furthermore, it can be based on the performance of the best-performing units, the average of all the units, or something between these two. Prices of the inputs and outputs, again, can be either market prices or shadow prices. Market prices are the prices paid by the customer for some goods or services, while shadow prices reflect the ratio of the prices as defined by Coelli et al. (2003, p. 26). Instead of the prices, also other value information of the inputs and outputs, such as company's preference information, can be used. For instance, Halme et al. (1999) have modelled decision maker's preferences by locating his or her most preferred combination of inputs and outputs, and incorporated that information in the efficiency analysis.

There are a number of ways to categorise benchmarking methods into different groups. For instance, Jamasb and Pollitt (2001) classify benchmarking models into frontier methods, such as Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), and Corrected Ordinary Least Squares (COLS), and average methods, for instance Ordinary Least Squares (OLS). Again, in CEPA (2003, pp. 14–15), benchmarking techniques are categorised into programming techniques, econometric techniques, and process approaches. The programming techniques are further divided into linear programming approaches, such as DEA and Parametric Programming Analysis (PPA), and index approaches, such as Partial Factor Productivity (PFP) and Total Factor Productivity (TFP). The econometric techniques are categorised into deterministic methods, such as COLS, and stochastic methods, such as SFA. The basic idea of the COLS is to estimate the production function statistically by OLS method, and to shift this efficient frontier by adding a value of the largest estimated negative error, as demonstrated in CEPA (2003, p. 31). SFA has similar characteristics as COLS, but it also contains a stochastic error term, which takes the noise of the input data into account, as shown by Jamasb and Pollitt (2003). The process approaches are divided into engineering economic analysis and process benchmarking, as shown in Table 2.1.

Table 2.1. Categorising the benchmarking techniques (CEPA 2003, p. 15).

Programming techniques	Linear programming approaches	Data Envelopment Analysis (DEA)
		Parametric Programming Analysis (PPA)
	Index approaches	Partial Factor Productivity (PFP)
		Total Factor Productivity (TFP)
Econometric techniques	Deterministic	Corrected Ordinary Least Squares (COLS)
	Stochastic	Stochastic Frontier Analysis (SFA)
Process approaches	Engineering economic analysis	Engineering Econometric Analysis (EEA)
	Process approaches	Process benchmarking

Somewhat similar to the former is the categorisation of the methods by Syrjänen et al. (2006, p. 17), where the models are categorised into parametric and non-parametric and into deterministic and stochastic, as presented in Table 2.2. In the deterministic models, such as the DEA, it is assumed that all the variations in the data affect the efficiency of the company, while in the stochastic models, for instance the SFA, a part of the variation can be interpreted as random noise.

Table 2.2. Categorisation of the benchmarking methods (Syrjänen et al. 2006, p. 17).

	Deterministic	Stochastic
Parametric	Corrected Ordinary Least Squares (COLS)	Stochastic Frontier Analysis (SFA)
Non-parametric	Data Envelopment Analysis (DEA)	Stochastic Data Envelopment Analysis (SDEA)

In this thesis, the practical examples and illustrations of the regulatory benchmarking are mostly based on the DEA, mainly since the development of the regulatory usage of that model has been carried out in Finland for several years. However, in this section, in addition to the DEA, a brief introduction is given to the SFA and EEA models, in order to compare the most important features of different kinds of models. These three models, DEA, SFA, and EEA, are selected here since they represent different approaches to the efficiency benchmarking. The DEA and SFA are both frontier methods; the DEA is non-parametric and deterministic, while the SFA is parametric and stochastic. The EEA, instead, represents an engineering approach, where the efficient cost level is based on the costs of the model company rather than the costs of the observed units. For more detailed theory and analysis of these and some other benchmarking methods, see for instance CEPA (2003), or Coelli et al. (2005).

2.2.1. Data Envelopment Analysis

Data Envelopment Analysis (DEA) was developed by Charnes et al. (1978) to evaluate the efficiency of non-commercial Decision Making Units (DMU). Since then, the method has become highly popular, and it has been used to analyse the efficiencies of all kinds of activities, from software development (Paradi et al. 1997) to baseball batters (Anderson and Sharp 1997)[2]. The regulators have also adopted the DEA, and it is or has been used by power sector regulators for instance in Denmark, Finland, Great Britain, Netherlands, Norway, Sweden, Australia, Brazil, and Columbia (Jamasb and Pollitt 2001).

The basic idea of the DEA is to measure the efficiency as the maximum of the ratio of weighted outputs to weighted inputs. Weights are chosen to maximise the efficiency score of each unit, with a constraint that the weights of one DMU shall not produce an efficiency score higher than one to any other DMU. Thus, a unit is defined as efficient if its efficiency score is 1 and efficiency scores vary between 0 and 1. Sometimes also percentage values are used (0–100 %). The mathematical formulation of the model is shown in Equations (2.2)–(2.4) (Charnes et al. 1978).

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[2] For a comprehensive DEA bibliography, see Emrouznejad (2001).

$$\max h_0 = \frac{\sum_{r=1}^{n} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{2.2}$$

subject to:

$$\frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1; \qquad j = 1,...,K \tag{2.3}$$

$$u_r, v_i \geq 0; \qquad r = 1,...,n; \qquad i = 1,...,m\,, \tag{2.4}$$

where

h_0	=	efficiency score of the DMU 0
y_{rj}	=	output r of the DMU j
x_{ij}	=	input i of the DMU j
u_r	=	weight of the output r
v_i	=	weight of the input i
n	=	number of outputs
m	=	number of inputs
K	=	number of DMUs

The basic DEA model described above is usually called the CCR model, named after its inventors Charnes, Cooper and Rhodes. In the object function above, Equation (2.2), the subscript 0 refers to the DMU, for which the efficiency score is calculated. However, the same DMU is referred to by its original number in the constraint functions. Actually, the nonnegative constraint of the weights u_r and v_i is not strict enough to ensure that the object function, Equation (2.2), has a definite value, as Cooper et al. (2002, p. 23) have shown. Furthermore, strictly positive weights are needed to ensure that companies, which achieve an efficiency score of one, are actually efficient. If the DMU is found to be efficient only in such a case, where one or more weights has to be zero, the DMU is called *mix inefficient* or *weakly efficient*, as shown by Cooper et al. (2002, p. 29). Hence, strictly positive weights are usually used.

A usual approach in DEA is to include all the companies in the data set that is used to form the efficient frontier. In such a methodology, efficient companies are reference companies for themselves also, and hence the efficiency scores of such companies cannot be higher than one. However, in some cases, it may be necessary to compare the efficiencies of the efficient companies. In the *super efficiency* model, a DMU for which efficiency score is calculated, is excluded from the peer group, that is, its information is not included in the restriction functions, as demonstrated for instance by Coelli et al. (2005, p. 200). By such a methodology, also efficiency scores higher than one can be found, and thereby the efficiencies of the efficient companies can be compared.

As Charnes et al. (1978) have shown, the fractional form of the DEA equation, presented above, can be replaced by a linear form, to be solved with linear programming computational methods. This linear form of the DEA is illustrated in Equations (2.5)–(2.8).

$$\max h_0 = \sum_{r=1}^{n} u_r y_{r0} \tag{2.5}$$

subject to:

$$\sum_{i=1}^{m} v_i x_{i0} = 1 \tag{2.6}$$

$$\sum_{r=1}^{n} u_r y_{rj} \leq \sum_{i=1}^{m} v_i x_{ij}; \qquad j = 1,\dots,K \tag{2.7}$$

$$u_r, v_i \geq 0; \qquad r = 1,\dots,n; \qquad i = 1,\dots,m \tag{2.8}$$

The CCR method described above assumes constant returns to scale. However, this assumption has to be relaxed in some cases, and hence, Banker et al. (1984) fine-tuned the DEA model by introducing a new variable, which enables to determine whether the unit is operating in increasing, constant, or decreasing returns to scale. This BCC model, named in the same way after its inventors (Banker, Charnes, and Cooper), is presented in Equations (2.9)–(2.13) (Banker et al. 1984).

$$\max h_0 = \sum_{r=1}^{n} u_r y_{r0} - u_0 \tag{2.9}$$

subject to:

$$\sum_{i=1}^{m} v_i x_{i0} = 1 \tag{2.10}$$

$$\sum_{r=1}^{n} u_r y_{rj} - u_0 \leq \sum_{i=1}^{m} v_i x_{ij}; \qquad j = 1,\ldots,K \tag{2.11}$$

$$u_r, v_i \geq 0; \qquad r = 1,\ldots,n; \qquad i = 1,\ldots,m \tag{2.12}$$

$$u_0 \text{ unconstrained} \tag{2.13}$$

As can be seen from the equations above, the only difference between the CCR and BCC models is the variable u_0 in the BCC model. According to Banker et al. (1984), the information about returns to scale can be determined based on the sign of u_0; if u_0 is smaller than zero, there are increasing returns to scale (IRS), while an u_0 greater than zero indicates decreasing returns to scale (DRS). If u_0 is equal to zero, the model is similar to the CCR model, and thereby the returns to scale are constant. Similarly, returns to scale can be limited to increasing, decreasing, constant, or variable by constraining the sign of u_0.

2.2.1.1. Weight restrictions in DEA

Usually, the only restriction for the weights of inputs and outputs in the DEA is that the chosen weights shall not provide an efficiency score higher than one for any DMU. Hence, there is great flexibility of weights in the DEA, and the weight of each DMU is chosen to show the unit in the best possible light. However, sometimes it may be useful to ensure that certain input or output parameters have appropriate importance in the efficiency analysis. There are a number of different methods to include weight restrictions or value judgements in the DEA, as shown for instance by Allen et al. (1997). In this section, absolute and relative restriction of weights, as well as restriction of the virtual inputs or outputs are discussed in brief.

As shown by Allen et al. (1997), the basic principle of the *absolute restrictions* of weights is to set fixed upper and/or lower limits for the weights of input and/or output parameters, as shown in Equations (2.14) and (2.15). These equations are added to the constraint functions for the chosen DEA model, illustrated in Equations (2.2)–(2.13).

$$\delta_i \leq u_i \leq \eta_i \tag{2.14}$$

$$\chi_i \leq v_i \leq \gamma_i, \tag{2.15}$$

where

u_i = weight of output i

v_i = weight of input i

δ_i = constant, representing the lower limit for the weight of output i

η_i = constant, representing the higher limit for the weight of output i

χ_i = constant, representing the lower limit for the weight of input i

γ_i = constant, representing the higher limit for the weight of input i

However, finding the optimal values for weight restrictions may prove problematic, since the value of the weights depend on the value of the input and output parameters, as shown by Joro and Viitala (1999).

In addition to absolute restrictions, weights can be controlled by *relative weight restrictions*. A usual approach is to set upper and lower bounds for the relation between the weights of two input or output parameters. This method is called Assurance Region (AR) method. If the restriction is set between the weight of two inputs or two outputs, the method is called AR I, while the method where the restriction is set between the weights of the input and output parameters is called AR II, as illustrated by Joro and Viitala (1999). AR I restriction is shown in Equation (2.16) and AR II restriction in Equation (2.17) as they have been presented by Allen et al. (1997).

$$\delta_i \le \frac{v_i}{v_{i+1}} \le \eta_i \tag{2.16}$$

$$\chi_i * v_i \le u_i\,, \tag{2.17}$$

where

δ_i = constant, representing the lower limit for the ratio of the weight of input i to the weight of input i+1

η_i = constant, representing the higher limit for the ratio of the weight of input i to the weight of input i+1

χ_i = constant, representing the limit for the ratio of the weight of output i to the weight of input i

Furthermore, weights can be restricted by *restricting virtual inputs or outputs*. A virtual output is the product of the weight and corresponding output parameter. Similarly, a virtual input is the product of the input parameter and its weight. The restriction of the virtual input or output is a relative restriction, where the upper and lower bounds for the ratio of a single virtual input (or output) to the total virtual input (or output) of the DMU is set. Equation (2.18) shows, the restriction of the virtual output (Allen et al. 1997).

$$\delta_i \le \frac{u_i y_i}{\sum_{i=1}^{n} u_i y_i} \le \eta_i\,, \tag{2.18}$$

where

n = number of outputs

u_i = weight of output i

y_i = output i

δ_i = constant, representing the lower limit for the ratio of the virtual output i to the total virtual output

η_i = constant, representing the higher limit for the ratio of the virtual output i to the total virtual output

2.2.1.2. Dual problem of DEA

Since DEA is basically linear programming problem, it is possible to find a dual problem for it. The optimal value of the object function, that is, the efficiency score, is obviously same in both the primal and dual case, but the additional information about the optimal solution can be achieved by solving also a dual problem. The dual problem of CCR DEA is demonstrated in Equations (2.19)–(2.22) as it has been presented by Cooper et al. (2002, p. 43).

$$\text{Min } \theta_0 \tag{2.19}$$

subject to

$$\theta_0 x_{0i} - \sum_{k=1}^{K} \lambda_k x_{ki} \geq 0\,; \quad i = 1,\ldots,m \tag{2.20}$$

$$\sum_{k=1}^{K} \lambda_k y_{kj} \geq y_{0j}\,; \quad j = 1,\ldots,n \tag{2.21}$$

$$\lambda_k \geq 0; \quad k=1,\ldots,K, \tag{2.22}$$

where

λ_k	=	weight assigned to peer unit k
θ_0	=	efficiency score of the DMU 0
y_{kj}	=	output j of the DMU k
x_{ki}	=	input i of the DMU k
n	=	number of outputs
m	=	number of inputs
K	=	number of DMUs

While the difference between CCR and BCC approaches in the primal model was a free variable, in this case, the difference lies in the sum of the lambdas. In the above-described CCR model, there are no restrictions for the sum of the lambdas. In the BCC dual, the sum of the lambdas is restricted to one. This is illustrated in Equations (2.23)–(2.27), where the dual problem of the BCC DEA model is presented (Cooper et al. 2002, p.88).

$$\text{Min } \theta_0 \tag{2.23}$$

subject to

$$\theta_0 x_{0i} - \sum_{k=1}^{K} \lambda_k x_{ki} \geq 0\,; \quad i = 1,\ldots,m \tag{2.24}$$

$$\sum_{k=1}^{K} \lambda_k y_{kj} \geq y_{0j}\,; \quad j = 1,\ldots,n \tag{2.25}$$

$$\sum_{k=1}^{K} \lambda_k = 1 \tag{2.26}$$

$$\lambda_k \geq 0; \quad k=1,\ldots,K \tag{2.27}$$

In addition, the increasing returns to scale model can be formulated by constricting the sum of the lambdas to be higher than one. Again, if this sum is forced to be lower than one, we have a decreasing returns to scale model (Cooper et al. 2002, pp. 134–135).

As it can be seen in the models described above, the major difference between the primal and dual problems is that in the primal problem, the weights of the inputs and outputs are optimised, while the peer group, that is, the group of the reference DMUs, is found in the dual model. Hence, determining the peer group also defines the weights of the parameters, and vice versa, since these are duals of each other in DEA. The reference DMUs constitute a virtual DMU, with which the performance of the inefficient DMU is compared. The value of the lambda in the dual problem is the weight by which a DMU participate in the constructing of the virtual DMU.

The primal model is in many cases referred to as a *multiplier form* of the DEA, while the dual problem is called an *envelopment form* (see for instance Coelli et al. 2005, p. 163). Furthermore, the dual problem may be called in the literature as a primal problem and vice versa (see for instance Charnes et al. 1994).

2.2.1.3. Advantages and disadvantages of DEA

One of the major advantages of the DEA is that the method is non-parametric, and thereby a priori definitions about the production function or prices are not needed. Consequently, it is easy to implement and more adaptive to changes in the dataset than the parametric methods. Furthermore, DEA scores are also easy to compute with programs that are available free of charge (CEPA 2003, p. 19). A further advantage of the model is that it provides a real peer group for inefficient companies (Syrjänen et al. 2006, p. 18), which may increase the plausibility of the method, as reported by CEPA (2003, p. 19).

Although the free variation of the weights is seen as one of the advantages of the DEA, the same issue can also be a disadvantage. Since weights are chosen to show each unit in the best possible light, a unit can appear to be efficient on the basis of only one efficient input or output parameter. This leads to one of the reported disadvantages of the DEA, which is that the efficiency scores tend to be sensitive to the selection of input and output parameters (CEPA 2003, p. 20). Furthermore, because of free variation of weights, the predictability of the model may become poor, since the effects of changes in the input or output parameters to the efficiency score are difficult to predict. To ensure that the most essential parameters have enough importance in the efficiency analysis, the weights of the parameters can be restricted, as shown above. However, when restricting the weights in the DEA model, the model is no longer purely non-parametric, and thus some of the most important advantages of the model may be lost. In addition to the weight issues, the inability to allow stochastic factors in the computation of the efficiency scores is considered one of the disadvantages of the DEA; see for instance CEPA (2003, p. 20) and Coelli et al. (2003, p.78).

In CEPA (2003, p. 21), it is stated that the DEA is suitable in the early stages of regulation, when the potentials of the cost reduction are mostly unknown. Somewhat similar is the suggestion of Jamasb and Pollitt (2001), who argue that frontier methods, such as DEA, SFA or COLS, seem to fit more in the setting of the efficiency requirement, while the average methods, such as OLS, are more suitable in the mimic competition between the firms with small cost differences.

2.2.2. Stochastic Frontier Analysis

As its name indicates, SFA is a stochastic benchmarking method. It is or has been used by the efficiency studies in the power sector for instance in Sweden, Australia (Jamasb and Pollitt 2000), and Finland (EMA 2007a). As stated by Coelli et al. (2005, p. 242), Aigner, Lovell, and Schmidt, but also Meeusen and van den Broeck proposed the SFA approach independently in the year 1977.

The fundamental idea of SFA is to include an error component in the efficiency evaluation by assuming that a part of the deviation from the efficient frontier is consequence of the noise in the input data. The model can be expressed in mathematical form as shown in Equation (2.28) (Coelli et al. 2005, p. 242).

$$\ln y_i = \boldsymbol{x}_i \cdot \boldsymbol{\psi} + \nu_i - \upsilon_i \tag{2.28}$$

Where

y_i	= output of the company i
$\boldsymbol{x}_i$	= vector containing the logarithms of the inputs of the company i
$\boldsymbol{\psi}$	= vector of parameters
ν_i	= symmetric error
υ_i	= non-negative variable associated with technical inefficiency

Since an inefficiency term is added, technical efficiency (TE) can be calculated as a relative value as shown in Equation (2.29) (Coelli et al. 2005, p. 244).

$$TE = \frac{y_i}{\exp(\boldsymbol{x}_i \cdot \boldsymbol{\psi} + \nu_i)} = \frac{\exp(\boldsymbol{x}_i \cdot \boldsymbol{\psi} + \nu_i - \upsilon_i)}{\exp(\boldsymbol{x}_i \cdot \boldsymbol{\psi} + \nu_i)} = \exp(-\upsilon_i) \tag{2.29}$$

Unlike DEA, SFA is a parametric model, which means that a priori definitions of the parameters are needed. For instance, the definition of the functional form and distributions of the inefficiency (υ_i) and noise (ν_i) parameters are needed. The fundamental differences of the inefficiency and noise parameters are that inefficiency parameter is one-sided, while noise is a two-sided parameter. In practice, this means that including noise in the model does not mean that companies are automatically granted better efficiency scores compared with models without noise. Since noise is double sided, the effect of noise can also decrease the efficiency score of the company, as shown by Syrjänen et al. (2006, p. 22).

2.2.2.1. Advantages and disadvantages of SFA

A major advantage of SFA is naturally the possibility to take the stochastic factors into account during the benchmarking process, as demonstrated in CEPA (2003, p. 35). Therefore, insufficient data quality can be compensated by assuming that not all the differences to the best practice are due to inefficiency, but some part can be interpreted as errors in the input data.

One of the obvious disadvantages of the parametric models is the need for a priori definitions. This also leads to sensitivity to misspecifications in the parameters. Furthermore, because of its complexity, the method may be difficult to implement in practice, and it can suffer from the lack of transparency, as reported by CEPA (2003, p. 36).

2.2.3. Engineering Econometric Analysis

The basic idea of EEA is to define a theoretically optimum model company and to compare the performance of the actual company to the calculatory performance of the model company. An example of such a model is the Swedish Network Performance Assessment Model (NPAM), where the reasonable revenue of each company is determined based on the costs of a fictitious network that is designed to serve the same customers as the actual network. The basic goal of this approach, according to Larsson (2005, pp. 27–28), is to calculate the values, such as connection, reliability, delivery, and grid administration that the distribution company produces to the customers. Based on these values, the reasonable revenues of the company can be determined. The input data of the model is the geographical location and delivered energy of every customer and every boundary point, that is, the connection point to generation or to other network, and the revenues generated from every customer and outage statistics of the company (Larsson 2005, p. 30). Based on this input data, the fictitious network is built, and its annual costs are calculated based on the asset values of the fictitious network.

A somewhat similar tool, called Reference Network Model, is or has been applied by the regulators in Chile, Argentina, and Spain. However, the difference to the NPAM approach is that, at least in the Chilean tariff revision 2000, the real network routes and transformers were given, and the model was used to optimise the required network investments (González 2004).

2.2.3.1. Advantages and disadvantages of EEA

The attractiveness of the EEA-type approach lies in the fact that consideration whether the best practice company is included in the dataset is unnecessary, since the best practice is defined theoretically, without company-specific information. Thereby also the number of the benchmarked companies is an irrelevant issue in such a model. This also reduces the regulator's dependency on the cost information of the companies, as stated by CEPA (2003, p. 37). In addition, since the cost function is built without company-specific information, possible regulatory gaming does not have an influence on the other companies' measured performance.

However, ignoring the existing network leads to a situation, where the companies are evaluated by assuming that distribution network has been constructed based on the present information about the technology, loads, and generation. The present network could be rather different compared with the optimal one built today; thus, the company may seem to be inefficient from the EEA model viewpoint. This may result from various reasons that are mainly uncontrollable for the present managers, for instance past investment decisions or future load growth, as discussed in Honkapuro et al. (2004a, 2004b) and Syrjänen et al. (2006, p. 18). In addition, as stated by Olson and Richards (2003), the starting point in the price cap regulation has to be based on the company's own cost information instead of the costs of the hypothetical or benchmark company, in order to provide companies reasonable opportunities to recover their costs.

Applying a hypothetical benchmark, instead of existing companies, is also a theoretically and philosophically problematic approach. For instance, Farrell (1957), a pioneer of the efficiency measurement, has suggested that for the complex process, such as a manufacturing firm, it is difficult to specify a theoretical efficiency function, and thereby it is preferable to compare the performances with the actual achieved performance than with some theoretical optimum.

A model of this kind may also be sensitive to even small changes in the input data. For instance, Wallnerström and Bertling (2007) have reported that small changes in the input data of the NPAM, for instance a minor change in the location or the energy consumption of one customer, may lead to considerable changes in the output of the model, that is, the allowed revenue of the company. The reason for this is that even the small changes may have significant effects on the structure, and thereby on the costs, of the whole reference network. The author of this thesis also has reported similar effects in the NPAM (Honkapuro et al. 2004b). Furthermore, when considering the practical aspects of this method, it is in many cases expensive to develop, as stated for instance by Syrjänen et al. (2006, p. 18). In addition, the input data needed from the companies could be rather detailed, as stated in CEPA (2003, p. 38). However, although this approach seems to have some significant disadvantages, as presented above, it could be useful for instance in determining the optimal horizon year network of a certain distribution area, and thereby it could assist in the definition of the long-term efficiency requirements. In addition, such an approach can be used as a tool to identify the relationships between the operational environment and efficient needs for assets, as reported by Burns et al. (2005).

2.3. Parameter selection

One of the most critical issues in the efficiency benchmarking process is the parameter selection, since it is obvious that companies put efforts into improving those parameters, which are included in the benchmarking. In addition, when the results of benchmarking are included in the regulatory calculations, there will be economic consequences for the variation of the benchmarking parameters; hence, these parameters will have a price. However, the significance of those parameters, which are not included in the efficiency benchmarking, will be lower.

When considering the parameters included in the efficiency benchmarking, it is essential that the parameters reflect the actual inputs and outputs that the companies use and produce, and the operational environment that they face. To minimise the gaming opportunities and trade-off effects, all necessary parameters should be included, but on the other hand, none of the parameters should be purposeless. If we consider electricity distribution, the most important function of a distribution company is to deliver energy to its customers. Therefore, such issues as the amount and quality of the delivered power or energy could be regarded as the outputs of the electricity distribution, while the inputs are in practice the issues needed for producing such outputs. Environmental parameters, such as geographical or climatic circumstances, are the ones that explain those differences in the performance of the companies, which are not a result of inefficiency. A relevant question is also what are the parameters that companies can actually control and which parameters have to be included in the benchmarking, but are outside the company's control. Parameter selection in the efficiency benchmarking of the electricity distribution companies is discussed in detail in section 3.2.

In addition to choosing the right parameters, a major question is also the appropriate number of benchmarking parameters. If there are too few parameters, some necessary information about the operational environment of the companies might be omitted, and thereby the efficiency scores of some companies could seem to be too low. However, increasing the parameters of the benchmarking also increases the number of the companies lying in the efficient frontier, and thereby some of the inefficiencies might not be identified. From the methodological point of view, the appropriate number of parameters depends on the number of benchmarked companies. For instance, Pahwa et al. (2002) suggest that a rule-of-thumb for the number of companies included in the DEA benchmarking should be equal or greater than three times the total number of the input and output parameters, as shown in Equation (2.30).

$$K \geq 3 * (m + n), \tag{2.30}$$

where

K	=	number of companies included in the benchmarking
m	=	number of input parameters
n	=	number of output parameters

On the other hand, Simar and Wilson (2000) have stated that the number of observations included in the benchmarking must increase at an exponential rate as the number of outputs increase. However, Pedraja-Chaparro et al. (1999) have stated that a simple rule for the number of parameters is not preferable, but the justification whether the sample size is large enough is more case specific. Nevertheless, if the number of companies is small, as is the situation in many countries, also the number of parameters has to be limited to only those that are the most important. As Shuttleworth (2005) has stated, the main problem in the benchmarking is the small number of the companies relative to potentially relevant explanatory variables. Thus, in many cases, compromises have to be made during the parameter selection.

An issue that should also be taken into account is the quality of the inputs and outputs. In this particular context, quality does not mean data quality, but the quality of the metered factors. For example, if the amount of labour hours is one of the inputs, the output achieved by using that input depends on the expertise and motivation of the labour force. As Farrell (1957) points out, technical efficiency reflects not only the efficiency of the management but also the quality of the inputs. Naturally, this is the impact that we desire; by using higher-quality inputs, company can produce more outputs and thereby be more efficient. However, in the case of the outputs, this could be a more problematic issue, since a higher quality of outputs may require a larger amount of inputs and thereby decrease the efficiency of the production. Therefore, increasing the efficiency by decreasing the outputs' quality should be prevented, either by including quality-related factors in the benchmarking or by introducing standard limits for the quality of outputs.

2.4. Conclusions on efficiency benchmarking

The measurement of efficiency, including issues such as the benchmarking methodology and parameter selection, has been discussed in this chapter. In a nutshell, it can be said that the key issues in measuring the efficiency of a company are: (1) choosing the input and output parameters included in the measurement, (2) determining weights for input and output parameters, and (3) defining the benchmark, with which the companies are compared. Parameter selection directs companies to perform better in those issues that are measured; furthermore, it may lead to trade-offs between the included and excluded parameters. The weights of the inputs and outputs are usually either market prices or shadow prices. The first of these are those prices that are actually paid for the measured inputs and outputs in the commercial markets. However, since these prices might be difficult to estimate for all the items, in many cases, shadow prices are used. These reflect the ratio of the prices of different inputs and outputs; in other words, they are the weights of these items. In addition to these, other value or preference information can be used as the weights of the inputs and outputs.

The benchmark, with which the performance of the companies is compared, is the efficient frontier, determined by the benchmarking method. In the frontier methods, the most efficient companies form an efficient frontier, while in the average methods, the benchmark is based on the average performance of the companies. However, in some methods, the benchmark can also be a fictitious, optimal company. Furthermore, in the non-parametric methods, the frontier is formed without a priori definitions, while in the parametric models, at least some assumptions, for instance about the shape of the frontier, are made beforehand. In addition, some of the performance differences to the efficient frontier can be interpreted as errors in the input data (stochastic methods), or it can be assumed that all the performance differences are a result of the inefficiency (deterministic methods). A brief comparison of the DEA, SFA, and EEA methods is presented in Table 2.3.

Table 2.3. Comparison of the DEA, SFA, and EEA methods.

Method	Advantages	Disadvantages
DEA	• No need for a priori definitions • Computation software widely available	• Varying shadow prices • Sensitive to the selection of the inputs and outputs
SFA	• Ability to take the noise in the input data into account	• Need for parameter definitions • Complexity of the model • Sensitive to parameter selection
EEA	• Number of the benchmarked companies can be small • Best practice always included	• Existing network is ignored • Expensive to develop • Detailed company-specific information needed • May be sensitive to small changes in the input data

However, when considering the directing signals of the performance measurement, the benchmarking methodology is not the only issue, but also the application of the benchmarking results in the regulatory calculations plays an important role. The reason for this is that regardless of what the parameters included in the benchmarking are, or how they affect the efficiency score of the company, it is the application of the results that defines the economic effects of the benchmarking, and thereby the marginal costs of the benchmarking parameters. On the other hand, these directing signals also depend on other incentive schemes in the regulatory framework, for instance the role of the quality of supply. These issues will be discussed in Chapter 3.

3. Incentive schemes in economic regulation

Regulation of the monopoly companies is in many cases represented as the principal-agent arrangement, where the principal tries to find an optimal contract for the agent, without comprehensive information about the agent's circumstances and behaviour, as described above. In this case, the regulator is the principal and the regulated companies are the agents. The objective of the regulator is to provide companies with incentives to maximise the total socio-economical welfare, while a company is thought to be interested solely in maximising the profits. Since the company has more information than regulator about the needed unit costs, for instance, the regulator cannot determine the exact cost levels of the companies, but its objective is to define the regulatory framework, which provides the companies with incentives to perform their operations by the most efficient way. In addition, the regulator has to ensure that the service quality of a monopoly company is at an appropriate level. In other words, the regulated companies have to be provided with incentives for efficiency and quality improvements. A common approach, applied for instance in Finland, is to focus first on the costs by including efficiency requirements in the regulatory framework, and then to introduce quality-related incentives in the more mature part of the regulation. There are at least two reasons behind this kind of an approach: First, it is usually easier to gather data on economic actions than on quality indices, and thus, they can be measured and compared from an early stage of regulation. Secondly, in many cases, the concern focuses on the price of electricity, especially if the quality is at an appropriate level already. However, the directing signals of such an approach, where cost efficiency is required, but quality is ignored, may be undesirable in the long term, since companies can decrease their costs at the expense of the quality of supply.

In this chapter, the role of the incentive schemes in the economic regulation is discussed. Hence, the theoretical background for the study is provided, and the first objective of the thesis, analysing the generating mechanisms of the regulatory benchmarking, is considered. In this context, incentive schemes are defined as mechanisms that are included in the economic regulation to provide companies with quality- and efficiency-related incentives. The major issues are thereby the role of efficiency benchmarking and quality in the economic regulation. However, the regulatory framework, in which these incentive mechanisms are implemented, has to be taken into account; therefore, the characteristics of regulation models are described in the early part of this chapter.

3.1. Regulation models

Regulation models can be classified in different ways. One approach is to divide regulation models into traditional *profit regulation* and *incentive regulation*. According to Vogelsang (2002), the term incentive regulation refers to a regulatory model, in which the regulator delegates certain pricing decisions to the regulated companies, and those companies can benefit from the profit increases that result from the cost reductions. The term Performance Based Regulation (PBR) is used often instead of incentive regulation in the US (Jamasb and Pollitt 2000). However, regulation models can be also divided into *bottom-up* and *top-down* approaches, where for instance profit regulation belongs to the first one, and price regulation to the latter one, as Kinnunen (2006) has illustrated. In addition, in Nemesys (2005b), division into *cost-recovery, fixed price, yardstick, auctions*, and *technical norm models* is made. A typical example of the cost-recovery model is profit regulation, while *revenue cap* and *price cap* regulation represent the fixed price models. However, as stated by Jamasb and Pollitt (2000), the described regulation models are rarely applied as such, but they typically occur in combinations of different models. In this chapter, the theory of profit regulation, price cap, revenue cap, and yardstick regulation are presented.

3.1.1. Profit regulation

The fundamental idea of profit regulation, such as *rate of return (ROR) regulation*, is that companies are allowed to collect the revenue that is sufficient to cater their typical operational and depreciation costs as well as the adequate return on the invested capital, as shown in Equation (3.1) (Jamasb and Pollitt 2000)

$$RR_{i,t} = OPEX_{i,t} + DE_{i,t} + T_{i,t} + \left(RB_i * ROR\right)_t . \tag{3.1}$$

Where

$RR_{i,t}$ = required revenue of the company i in year t

$OPEX_{i,t}$ = operational expenses of the company i in year t

$DE_{i,t}$ = depreciation expenses of the company i in year t

$T_{i,t}$ = tax expenses of the company i in year t

RB_i = rate base of the company i

ROR = rate of return

Basically, profit regulation is a simple and light-handed form of economic regulation, and therefore it is a common approach as the first regulatory framework after re-regulation. However, since the earnings of a company are linked to the value of its asset base, the method encourages companies to overcapitalisation; this is known as the Averch-Johnson-effect. Therefore, the method is also criticised for directing companies to strive for superoptimal reliability levels (Ajodhia and Hakvoort 2005). Nevertheless, although this statement is based on the fact that network investments and the quality of supply go hand in hand, there are no guarantees that investments are the ones that increase reliability the most. Thus, the regulation of the quality of supply may also be needed in the ROR regulation. However, the ROR regulation suffers from the lack of efficiency incentives (Jamasb and Pollitt 2000). Therefore, the directing signals of the plain profit regulation do not meet one of the primary aims of the restructuring process of the industry, which is increasing the efficiency of the industry, and this is why such a regulation model in its pure form is not seen as an attractive option in the long term.

However, the directing signals of the profit regulation can be improved by efficiency benchmarking. For instance in Finland, efficiency benchmarking is used in the ROR regulation to set an efficiency requirement for the operational costs. This way, one of the disadvantages of the ROR regulation, that is, the lack of efficiency incentives can be overcome. Nevertheless, this approach does not affect the incentives for overcapitalisation, but may even worsen this problem by introducing incentives for trade-offs between OPEX and CAPEX and encourage companies for instance to book operational costs as investments in an unclear situation.

However, these gaming opportunities and incentives for too high investment levels can be decreased by including also capital costs in the benchmarking process.

3.1.2. Price cap regulation

The basic idea of the price cap regulation is to set a price ceiling, based on the Retail Price Index (RPI) and the efficiency factor X, as shown in Equation (3.2) (Jamasb and Pollitt 2000)

$$P_{i,t} = P_{i,t-1} * \left(1 + RPI - X_i\right) \pm Z_i \,. \tag{3.2}$$

Where

$P_{i,t}$ = price ceiling of the company i in year t

RPI = retail price index

X_i = efficiency factor of the company i

Z_i = correction factor for events beyond management control for the company i

Price cap *P* represents an index of different tariffs of the regulated company, as clarified by Jamasb and Pollitt (2000). As for instance Joskow (2006) has shown, some type of cost-based regulation is typically used for setting the initial price ceiling in the model. Hence, price cap regulation is typically implemented after the regulator has gathered some experiences from the typical costs of the industry by applying profit regulation.

Price cap regulation, similarly as revenue cap regulation that will be introduced next, provides companies with efficiency incentives; this is because a company's prices are separated from its costs, and the regulated company can retain the achieved efficiency gains during the regulatory period. Although there are strong incentives for efficiency improvements in the price regulation, the reasonable sharing of the efficiency gains between the company and the customers has to be solved. In practice, this is related to the selection of the X-factor, as Olson and Richards (2003) present that X-factor is a mechanism, by which customers receive benefits from the expected productivity growth of the companies. However, updating the X-factor and the cost base at the turn of the regulatory period may lead to regulatory gaming, since a company with high performance may face a demanding incentive scheme in the future, and hence is reluctant to provide the regulator with the performance information, as illustrated by Laffont and Tirole (1988). In addition, Jamasb et al. (2003) have stated that the periodic review in the price cap regulation provides companies with incentives to increase or decrease the value of the regulatory asset base or costs base before the tariff review. Coelli et al. (2003, p. 77) share this view and suggest that one solution for this gaming problem could be to fine-tune the regulatory model such that the companies can benefit from the efficiency gains for a longer time. Furthermore, in a regulation model of this kind, there are risks that utilities tend to increase profits by neglecting quality issues; see for instance Viljainen (2005, p. 19), Ajodhia and Hakvoort (2005), or Olson and Richards (2003). Therefore, the regulation of the quality of supply is of particular importance, when the economic regulation focuses on the price instead of the profit. Price cap regulation is also criticised for encouraging companies to increase their selling and thereby providing conflicting incentives against energy efficiency programs (Biewald et al. 1997, p.52).

3.1.3. Revenue cap regulation

The basic idea of revenue cap regulation is to define the allowed revenue, as shown in Equation (3.3) (Jamasb and Pollitt 2000)

$$R_{i,t} = \left(R_{i,t-1} + CGA_i * \Delta Cust_i\right) * \left(1 + RPI - X_i\right) \pm Z_i \,. \tag{3.3}$$

Where

$R_{i,t}$ = allowed revenue of the company i in year t

CGA_i = customer growth adjustment factor (€/customer) of the company i

$\Delta Cust_i$ = change in the number of customers of the company i

RPI = retail price index

X_i = efficiency factor of the company i

Z_i = correction factor for events beyond management control for the company i

As it can be determined based on the equations for price cap and revenue cap regulation, the fundamentals of those two regulation models are quite similar. Therefore, also the directing signals of the revenue cap regulation are mainly similar to those of the price cap. However, in this case, unlike in the price cap regulation, there are not incentives for increasing the amount of delivered energy, since it is revenue, instead of prices, that is limited.

3.1.4. Yardstick regulation

The basic idea of yardstick regulation is to compare companies against each other and determine the allowed incomes based on the performance of the company. In Equation (3.4), the main elements of the cost-based yardstick regulation are demonstrated (Jamasb and Pollitt 2000)

$$P_{i,t} = \alpha_i C_{i,t} + (1-\alpha_i)\sum_{j=1}^{K}\left(f_j C_{j,t}\right). \tag{3.4}$$

Where

$P_{i,t}$	=	overall price cap for the company i in year t
α_i	=	share of company's own cost information for the company i
$C_{i,t}$	=	cost of the company i in year t
f_j	=	weight for the peer group company j
$C_{j,t}$	=	cost for the peer group company j in year t
K	=	number of companies in the peer group

Yardstick regulation can be used to introduce indirect competition between companies operating in different geographical areas, as stated by Jamasb and Pollitt (2000). Thus, it provides companies with incentives to cut their costs. The risk that companies cut their costs by neglecting quality issues can be reduced by including quality in the performance benchmarking. Such an approach could be even closer to the real market base competition, since the price is not the only issue, but also the service quality matters in the competition between the companies. In addition, yardstick regulation decreases the information asymmetry between the companies and the regulator, since the regulator can estimate the appropriate cost levels of the companies by comparing them against each other. However, differences in the operational environment of the companies have to be taken into account in the comparisons to minimise the risks, which are related to the costs variations that are due to the differences in such factors as geography, climate, or population density (Vogelsang 2002). In addition, there is a concern that companies might collude in the yardstick regulation, and by that way affect the efficiency requirements. However, as stated by Burns et al. (2005), such behaviour is not likely in the electricity distribution business, since the number of companies is usually high enough to ensure that tacit agreements are difficult to maintain, and on the other hand, benefits of such agreements would be lower in the regulated industry than in the competitive business. In practice, yardstick regulation can be used in connection with other methods, for instance in the price adjustments for the price cap regulation, as Vogelsang (2002) has reported.

3.2. Efficiency benchmarking in economic regulation

Based on the properties of the basic regulation models, some kind of efficiency measurement is usually needed in these models to satisfy all the requirements of the economic regulation. Profit regulation suffers from the lack of efficiency incentives and encourages companies to overcapitalisation. This problem can partly be alleviated for instance by estimating the reasonable operational costs by efficiency comparisons. Furthermore, in RPI-X style regulation, that is, price or revenue cap, efficiency measurement is usually needed to determine the X-factor. In addition, benchmarking has obviously an essential role in the yardstick regulation. Therefore, efficiency measurement is usually needed in all these forms of economic regulation. Furthermore, one of the key concerns in the regulation of natural monopolies is the asymmetry of the information between the regulator and regulated companies (cf. Jamasb et al. 2003). Hence, efficiency benchmarking can be used as a tool to compare companies against each other, in order to find the cost levels of the most efficient companies and the cost reduction potential of the inefficient companies. It is obvious that the comparison of the companies brings market-like forces in the monopoly sector, since it creates competition between these companies. However, the effects of the benchmarking for regulated companies depend on the role of the benchmarking in the regulatory framework. If benchmarking is implemented in yardstick regulation, its role to put up competition between the companies is stronger than in RPI-X regulation. Viljainen (2005, p. 33) has suggested that the role of benchmarking might be changing in the future from a tool that determines company-specific efficiency requirements to a method to create pseudo-competition in the monopoly sector.

The basic idea of efficiency benchmarking, as it has been shown above, is to determine the efficiencies of the companies as the ratio of the outputs they produce to the inputs they use. In addition to the inputs and outputs, some environmental parameters are needed to ensure that different operational environments of the companies are taken into account in the benchmarking process. Hence, the selection of these parameters is essential in the design of the benchmarking process. Other relevant issues are the characteristics of the benchmarking methodology and the implementation of the results in the regulatory calculations. Treating of the outliers and the effects of the scale of operation are the issues that are dependent on the benchmarking methodology. The economic effects of the benchmarking, again, are strongly dependent on the methodology that is used to apply the results to the regulatory calculations. Hence, all the issues presented above are highly relevant when considering the directing signals of the regulation.

3.2.1. Input parameters

In electricity distribution, inputs are efforts that are required to deliver electric energy to the customers. In practice, this means the building, operating and maintaining of the electricity distribution network, where the major components are lines and transformers. Therefore, it is not a surprise that in a comprehensive study by Jamasb and Pollitt (2001) concerning efficiency measurements in the electricity distribution, the most frequently used input parameters turned out to be the number of employees, transformer capacity, the length of the network, and operating costs. These parameters seem to fall in the main categories of inputs, defined by Coelli et al. (2003, p. 84), which are labour, capital, and other inputs. Again, if inputs are measured as monetary quantities, they can be divided into operational and capital costs. Korhonen and Syrjänen (2003) have suggested that measuring the inputs as costs is a useful option to simplify the process and to compare companies with different principles of operation, that is, outsourcing, for instance.

Efficiency benchmarking, used in the electricity distribution, is usually input-oriented. Hence, it is assumed that efficiency is mostly achieved by decreasing the amount of inputs, and outputs are considered to be outside the company's control. Therefore, efficiency benchmarking directs companies to decrease the amount of input parameters, and hence the choosing of input parameters has significant effects on the directing signals of the benchmarking. However, it is also important to consider the role of the parameters that are not included in the benchmarking, since excluding some parameter from the benchmarking may provide companies with incentives to strive for efficiency gains by trade-offs. For example, if operational costs are an input parameter in the efficiency benchmarking, but the capital costs are not included in the benchmarking process, as was the case for instance in the former benchmarking model used in Finland, companies may seek efficiency gains by favouring replacement investments instead of maintenance works. In addition, using only operational costs as the input of the benchmarking may affect the profitability of the outsourcing, since some part of the capital costs is usually shifted to the operational costs in the outsourcing process. For example, if the company decides to lease new energy meters, operational costs will be higher and capital costs lower, compared with the case where the company purchases them. On the other hand, a benchmarking model of this kind also encourages companies to modify their bookkeeping practice so that in unclear cases, expenses are booked as investments rather than operational costs. The purpose of this kind of behaviour is naturally to show the company in a more favourable light. However, as Jamasb et al. (2003) have pointed it out, this regulatory gaming might affect also the measured performance of other companies, not only the performance of the gaming company.

The question is not only what the inputs of the efficiency measurement are, but also what the most suitable methodology is to include these parameters in the benchmarking process. If the number of benchmarking parameters has to be limited, as the case usually is, combining the inputs as one parameter is a relevant option. In addition, as for instance Giannakis et al. (2005) have stated, company receives an efficiency score of 1, that is, it is found efficient, if it sets the efficient frontier for one input or output, no matter how low its performance is with respect to other parameters. Hence, an inefficient company may appear to be efficient because of only one deviating input or output parameter. Furthermore, the directing signals of the benchmarking become clearer, if all the inputs are combined as one parameter. That is because the shadow price is in that case equal for every input parameter, and hence company can better predict the consequences of the changes in the input parameter, compared with a situation where shadow prices of the input parameters are different. In addition, if service quality, operational costs, and capital costs are treated separately, companies may be provided with distorted incentives, and hence they may adopt inefficient mix of parameters, as stated by Giannakis et al. (2005). Furthermore, as Shuttleworth (2005) has illustrated, separate benchmarking of OPEX and CAPEX may lead to an estimate of the efficient cost combination that is infeasible. In contrast, if all these parameters are treated equally in the efficiency benchmarking, the incentives of the efficiency evaluation are in line with the objective of the network design, that is, minimising of the total costs.

3.2.2. Output parameters

The main outputs of the electricity distribution company can be defined as the quantity and quality of the delivered energy, and hence, using the amount of the delivered energy as the output of the efficiency benchmarking appears to be a natural approach. However, it can be discussed whether the amount of delivered energy is a correct parameter to reflect the costs needed for the distribution of electricity. Since the network components have to be dimensioned based on the peak load of the network, this could be considered as the output that reflects more accurately the needed inputs than the delivered energy. For instance, Burns and Weyman-Jones (1996) have found out that the main cost drivers for the electricity distribution are the number of customers and the maximum demand.

Since the input-oriented benchmarking is mostly used in the electricity distribution, it is assumed that the output level is given and efficiency is achieved by minimising the inputs. Nevertheless, efficiency gains can also be achieved by increasing the outputs, and further, increasing the amount of the delivered energy or peak load, is not desirable from the socio-economic point of view. Therefore, it should be ensured that efficiency benchmarking does not provide incentives that discourage the use of the demand side management (DSM) or increasing the energy efficiency.[3] However, the consequences of increasing the outputs could be difficult

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[3] The same type of negative impacts for energy saving in the case of price cap regulation is discussed in section 3.1.2.

to predict in an input-oriented model, and hence the incentives for increasing the outputs are usually slighter than incentives for decreasing the inputs.

In addition to the amount of energy or the size of the peak load, a significant output of the distribution company is also the quality of service, which will be discussed more in section 3.5.

3.2.3. Environmental parameters

In addition to the input and output parameters, parameters describing the operational environments of the companies are usually needed. For instance Coelli et al. (2003, p. 89) have shown that the amount of the delivered energy does not provide complete information about the costs needed for the electricity distribution; these costs also depend on the geographical locations of the customer. That is, the costs are not the same, if the same amount of energy is delivered to 100 customers in the area of one square kilometre or to 1000 customers in the area of 100 square kilometres. Therefore, also information about the geographical conditions of the company is needed; that data is usually provided by including such parameters as the network length and the number of customers in the benchmarking to describe the operational environment of the company. For example, Jamasb and Pollitt (2001) have found out in their comparison of the benchmarking studies that delivered energy, the number of customers and the size of the service area are the most widely used outputs. In practice, environmental parameters are usually treated, for instance in DEA, as outputs.

As it was discussed above, the number of benchmarked companies limits the number of parameters that can be included in the benchmarking. Therefore, it is likely that not all the parameters that affect the operational environment of the distribution company can be included in the benchmarking parameters, and the selection of the parameters is more or less a compromise. If some environmental parameter cannot be included directly in the efficiency benchmarking, some other methodology may be considered to take into account the effects of such a parameter in the regulatory calculations. For instance, Coelli et al. (2003, p. 92) suggest that if the environmental parameter is such that it is likely to affect only one or two companies, the regulator can negotiate with the companies to find the amount for which the efficiency score should be adjusted for those companies to compensate the unfavourable operational environment. However, if the number of the companies that are likely to be affected by the same environmental parameter is high enough, then Farrell's (1957) suggestion that observations could be divided into homogenous groups based on the operational environment can be relevant. In addition, multiple output parameters can be combined into a single "Composite Size Variable", as illustrated by Shuttleworth (2005).

3.3. Capital costs in regulation and efficiency benchmarking

Since electricity distribution is capital-intensive business, the role of capital costs in regulation and benchmarking is one of the key issues in the regulatory design. Network investments have significant effects on the costs and quality of electricity distribution. Hence, companies should spend enough money in network investments in order to maintain an appropriate condition of the network and a proper level of the quality of supply. On the other hand, investment levels should not be too high to avoid an increase in prices. Asset lifetimes in electricity distribution are long, typically several decades, and hence there is time lag between the investment decisions and the improvement or deterioration of quality, as reported by Ajodhia and Hakvoort (2005). Therefore, a decreased investment level does not immediately affect the quality of supply, and it is also time consuming to increase the quality levels. Hence, there are risks that companies may seek short-term efficiency gains by neglecting network investments, if the incentive for such behaviour is included in the regulatory model. In addition, development of the other infrastructure affects the investment needs of the distribution companies; extension investments are in many cases needed to satisfy the increasing demand, and for instance, roadwork could have effects on the timing of the replacement investments. Because of the issues described above, including the capital costs in the regulatory process is one of the most difficult tasks in the design of a regulation and benchmarking model.

A major target in the design of a distribution network is to minimise the total costs during the lifetime of the network, within the technical boundaries. The cost-minimisation target can be expressed in mathematical form as presented in Equation (3.5).

$$C_{tot} = \int_0^{\tau} \left(OPEX(t) + CAPEX(t) + IC(t) \right) dt \, , \tag{3.5}$$

where

C_{tot}	= total costs
$OPEX(t)$	= operational expenses in year t
$CAPEX(t)$	= capital expenses in year t
$IC(t)$	= interruption costs in year t
τ	= lifetime of the network

To ensure that economic regulation, as well as benchmarking as a part of the regulation, provides directing signals, which are in line with the design principles, all the cost items of Equation (3.5) should have a similar effect on the regulatory outcomes. As Jamasb et al. (2003) have stated, if the capital costs are not included in the benchmarking model, there are incentives to shift assets from the competitive business to the regulated parts of the company and to increase certain output parameters, such as network size. In addition, Giannakis et al. (2005) have stated that in the regulatory model used in the UK, companies receive higher benefits from reducing their OPEX than from equal savings in CAPEX, and because of that, companies may seek an increase in allowed revenues by capitalising OPEX. Therefore, to minimise the gaming opportunities and to provide companies with incentives to minimise their total costs, all the cost items should have an equal effect on the allowed incomes. However, taking the capital costs into account in the efficiency analysis may turn out to be a difficult task, including difficulties concerning practical issues, such as data collecting, and problems in the directing signals.

Using the accounting records of the companies as the basis for determining the capital expenses may seem to be the obvious option. However, there are numerous issues that complicate the use of the accounting records as a source of the company's capital expenses. Coelli et al. (2003, p. 86), for instance, name issues such as the effect of the inflation and differences between the depreciation schedules of the companies as possible traps in the process of collecting the data of the capital expenses.

Because of the difficulties in comparing the capital costs of the companies, an attractive option could be to use physical quantities instead of monetary values, which for instance Jamasb and Pollitt (2001), have found as a usual approach in the most benchmarking studies. Nevertheless, there are problematic issues also in the physical measures; for instance, there are number of different transformers and lines, in other words, there is heterogeneity of commodities, as shown by Coelli et al. (2003, p. 86). If the number of input parameters has to be limited, the use of the monetary values would be better option, since in that case all the capital items can be bundled as one input parameter. One approach to combine the physical and monetary measures would be to determine the actual repurchase value of the network based on the amounts and prices of the components and define the capital costs based on that value, as it is done for instance in Finland.

However, regardless of whether capital costs are based on the physical quantities, the repurchase value of the network assets, or bookkeeping value, the problem is that they reflect the past investments. Therefore, because of historic overinvestments, a company may have a tight efficiency requirement, which, again, could be caused by misspecifications in the load growth forecasts, for instance. In addition, the value of the network assets could be higher than optimal also because of the decrease in population in the network area or closing down of a large industrial plant. One solution for this problem could be the use of the optimised repurchase value in the capital that is applied in the efficiency measurement, as stated by Coelli et al. (2003, p. 111). The basic idea in that approach is to replace the capital of the company by the optimised value of the capital, where the current information on the issues such as load demand, are taken into account. By that way, it can be ensured that an oversized network, which could be due to a load decrease or mistakes in the past investment decisions, does not decrease the efficiency of the company, and hence the present managers do not suffer from the mistakes of the past. However, as Coelli et al. (2003, p. 112) recommend, an approach of this kind should be avoided, since there is a considerable amount of subjective judgment involved.

Instead of the value of the network assets, the cost of the capital used in the benchmarking can also be based on the annual network investments. However, using annual investment costs as a benchmarking parameter also contains difficulties. If the aim is to measure the efficiency of the total costs, the problem is to combine different types of cost items; investment costs that impact the whole lifetime of the investment and annual costs, such as operational or interruption costs. In addition, investments of the network companies are in many cases quite lumpy, in other words, investment costs vary greatly between the years, which further complicates the issue. However, since including the investments in the benchmarking provides companies with incentives to reduce their network investments, the directing signals have to be analysed carefully to ensure that companies do not neglect the necessary investments.

3.4. Efficiency requirements

The approach of this thesis is to discuss the efficiency benchmarking as a tool to produce an efficiency requirement for regulated companies, that is, the X-factor in the RPI-X style regulation. The efficiency requirement should reflect the annual efficiency potential of each regulated company. This efficiency potential is a consequence of two issues, viz. the efficiency gaps between the companies and the productivity growth in the industry. Therefore, the efficiency requirement can be divided into individual and general parts; the individual efficiency requirement is based on the efficiency potential of each company compared with other companies, while the general part of the X-factor is based on the expected productivity growth in the whole industry. Thus, the roles of these requirements can be considered to be the following: the general part ensures that the productivity growth of the industry is in line with the expected growth rate, whereas the function of the individual part is to ensure that the efficiency differences of the companies will decrease so that inefficient companies will catch up with the most efficient ones.

If the X-factor is derived solely from the company’s past performance, the incentives for the efficiency improvements vanish, as pointed out by Coelli et al. (2003, p. 8). This is because the company is not interested in improving its efficiency, if the result of such a behaviour will tighten its efficiency requirements. Therefore, the approach in determining the individual efficiency requirement should be the estimated efficiency potential of the company, not the past efficiency improvements.

The general efficiency requirement is based on the expected production growth in the industry. However, as stated by Coelli et al. (2003, pp. 19–20), if the general efficiency requirement is based on the average production growth of all the companies, it includes also the catch up-element, and thus the requirement will be too tight for the frontier companies. Therefore, a typical approach is to estimate the general efficiency requirement based on the frontier shift in the efficiency benchmarking. This frontier shift, which is sometimes also referred to as a technical change, reflects the efficiency improvement of the most efficient companies. The assumption is that all the companies are able to increase their productivity for at least the same amount as the most efficient companies have done.

3.4.1. Deriving efficiency requirements from efficiency scores

When implementing the efficiency requirements in the regulatory calculations, it should be noticed that some part of the efficiency gaps could be closed within a short time period, while part of the efficiency gains can be achieved only during a long time. In practice, this obviously depends on the cost components, on which the efficiency requirement is focused. Typically, efficiency improvements in the operational activities can be achieved within a few years, while increasing the efficiency of the capital costs could take decades because of long asset lifetimes. Burns et al. (2005) have demonstrated this by presenting that two generic types of the benchmarking model are available. In the short-run model, the efficiency of the operational expenditures is evaluated by using network characteristics and usual customer services as output parameters. In the long-run model, efficiency is judged according to total costs, and services provided by the company represent the outputs. Distribution companies should be provided with incentives for both long and short-term efficiency improvements; however, the short-term efficiency gains should not jeopardise long-term development. In practice, this issue should be considered when designing the methodology that is used to derive the efficiency requirements from the efficiency scores.

Shuttleworth (2005) suggests that benchmarking can be used as a preliminary step in the company-specific investigations, but cannot replace any detailed investigations. In addition, Coelli et al. (2003, p. 72), state that the efficiency score should only be a basis in the determination of the X-factor, and final decision should be done based on the benchmarking results and the discussions between the regulator and the company. However, if the number of the companies is large, company-specific discussions are laborious. Therefore, for instance in Finland, X-factor is defined solely based on the results of the efficiency benchmarking. However, in such a case, it could be reasonable to include some error marginal in the efficiency requirement to ensure that possible errors in the input data do not lead to overestimated efficiency requirements, especially if the efficiency benchmarking method assumes all the deviations in the input data as efficiency differences.

3.4.2. Focus of the efficiency requirement

Efficiency requirement can focus either on the individual cost components or on the total revenue of the company. The approach naturally depends on the regulation model; if the applied regulation is revenue cap in its pure form, it is obvious that the efficiency requirement is focused on the total revenue of the company. In the ROR-type regulation instead, efficiency requirement can be focused on the operational costs, as in Finland for instance. Focusing the efficiency requirement on the total revenue is seen a more beneficial option by Viljainen (2005, p. 40), because this approach does not favour any operational model. Therefore, companies have freedom to choose, which cost components they are willing to decrease.

To ensure well-defined directing signals of the economic regulation and an understandable relation between the efficiency measurement and efficiency targets, the input parameters of the benchmarking should correlate with the object of the efficiency requirement. In other words, the indicated efficiency potential in one subject should lead to an efficiency requirement for the same subject. Therefore, if the efficiency benchmarking is used to define the efficiency requirement that focuses on the total costs, these total costs should also be an input parameter in the benchmarking. On the other hand, if such an efficiency requirement focuses only on the operational costs, it is more suitable to focus only on the efficiency of the operational costs in the benchmarking also.

As an example, the role of the efficiency benchmarking in the Finnish regulatory model is illustrated in Fig. 3.1. This model will be described in detail in Chapter 6.

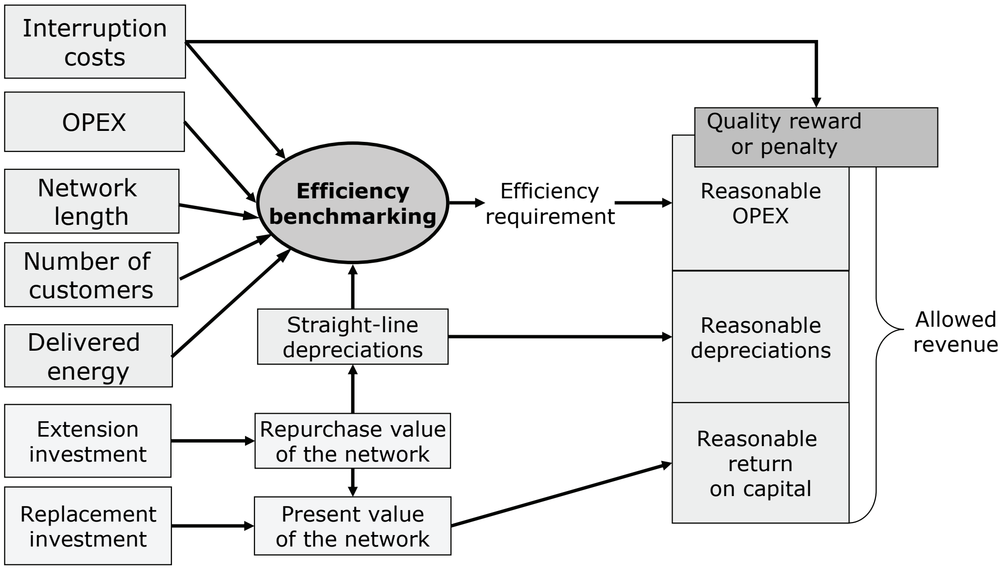

Figure 3.1. Role of efficiency benchmarking in the Finnish regulatory model.

In the model described above, total cost, which is the sum of the operational costs, interruption costs, and straight-line depreciations, forms an input parameter of the benchmarking. Delivered energy is an output parameter, while the number of customers and the network length are environmental parameters. However, unlike it has been presented earlier, the input parameter and focus of the efficiency requirement are not the same in this model, but the efficiency requirement focuses on the operational costs although the input parameter is total costs.

3.5. Quality in economic regulation

As mentioned above, quality in the power supply can be divided to three issues; (1) reliability, which is often referred to as continuity of supply, (2) voltage quality, and (3) quality of customer services. However, classification between the different groups of quality could be problematic in some cases. For instance Rivier and Gómez (2000) propose that interruptions shorter than three minutes are considered a voltage quality problem; they admit however that those interruptions could also be classified as a continuity of supply problem. Again, Partanen et al. (2005b) categorise such short interruptions unambiguously into the category of the continuity of supply. Another problematic issue are voltage dips. The impacts of dips on customers are quite similar to the impacts of short interruptions; however, if the supply is not interrupted, the dips are categorised more likely as voltage quality problems. When considering practical aspects, dips are more difficult to register, since, unlike in the case of interruptions, registering of dips cannot be based on the breaker activity, but a voltage quality meter is required. This also supports the view that dips could be categorised into voltage quality problems. Regulation of the voltage quality is usually based on standard limits, while economic regulation usually concentrates only on the continuity of the supply, and on the quality of customer service in some cases. However, this study focuses only on the continuity of supply. To avoid any confusion, short interruptions are considered as a continuity of supply problem, while voltage dips are categorised as voltage quality issues in this thesis.

Ajodhia and Hakvoort (2005) divide quality regulation instruments into three categories: (1) indirect instruments, (2) standards, and (3) incentive schemes. The basic idea of an indirect instrument is to strengthen the information and negotiation position of the customers. In practice, this can be achieved by publishing information about companies' performance or strengthening the customer's position by customer committees. Standards can be used to set boundaries for the quality levels, and violation of the standards can lead to a fine or tariff rebate. In incentive schemes, a company's quality is compared with the quality target, and a difference between these two leads to a penalty or a reward. The major difference to the standards is that the relationship between the penalty (or reward) and quality is in this case usually continuous, while it is discrete in the case of standards. In addition to the formal quality regulation, there is also the spill-over effect, which provides companies with quality-related incentives. In other words, the quality reputation of a monopoly company spills over to the competitive business, and thus the companies are pressurised to keep their quality level in line with the demands of the customers, as indicated by Ajodhia et al. (2006).

3.5.1. Objectives of quality regulation

As economic regulation moves towards stricter price regulation, it encourages companies to reduce their cost, and is hence likely to lead to decreasing quality levels (Ajodhia and Hakvoort 2005). For instance, Ter-Martirosyan (2003) has found that incentive regulation in the US is associated with an increase in the average duration of outages. In addition, society's dependency on the uninterrupted power supply has increased strongly during the past decades. Therefore, regulating the quality of supply has become more and more significant.

As Ajodhia and Hakvoort (2005) have shown, quality is optimal from the viewpoint of a monopoly company, if its profits are maximised. Again, from the socio-economic perspective, quality is optimal if the marginal costs to produce quality are equal to the marginal benefits of the improved quality. To direct companies to optimise their quality level, economic regulation should ensure that companies' profits are maximised, when the quality of supply is at an optimal level from the socio-economic point of view. If we consider the costs and benefits of the quality improvements, the costs are obviously companies' capital and operational costs, required to improve the quality. A benefit, then, is a decrease in the costs incurred by the customers caused by the imperfect quality of supply, in other words, customers' interruption costs. The theoretical relation between the quality and distribution costs is illustrated in Fig. 3.2, as presented by Lakervi and Holmes (1995, p. 14).

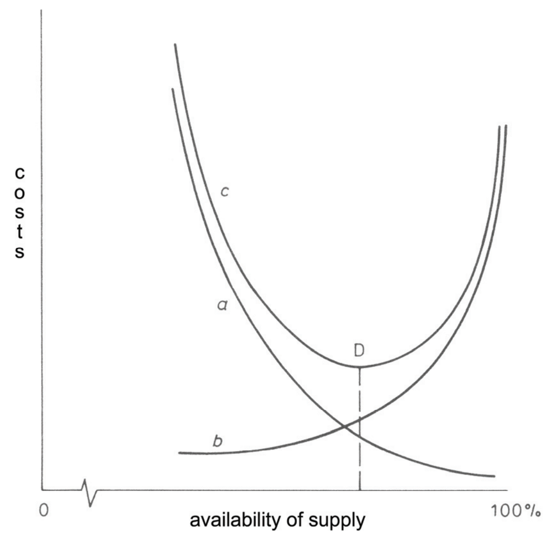

Figure 3.2. Theoretical dependence between the availability of the supply and the costs of the electricity distribution (a = interruption costs incurred by the customers as result of loss of supply, b = costs of the distribution company, c = total costs, D = minimum of the total costs), Lakervi and Holmes (1995, p. 14).

The socio-economic optimum level, where the marginal costs of the quality improvements are equal to the marginal benefits of the reductions in the interruption costs, is the point where the derivative of the company-specific cost function is equal to the negative derivative of the interruption cost function, as shown in Equation (3.6).

$$\frac{d}{dPQ}\left(OPEX + CAPEX\right) = -\frac{d}{dPQ}IC \tag{3.6}$$

Where

$OPEX$	= operational expenses of a company
$CAPEX$	= capital expenses of a company
IC	= interruption costs of the customers
PQ	= power quality

As stated above, economic regulation should ensure that the companies' profits are maximised in the optimal point defined above, in order to direct companies to strive for the socio-economic optimum quality. In practice, this means that regulation should direct companies to carry out those development actions, in which the annual capital and operational cost is smaller than the reduction in the annual interruption costs. Naturally, this is the primary aim of the long-term planning of the distribution networks also. However, in many cases, cost components have different effects in the economic regulation. Therefore, it is not obvious that companies' profits are maximised by minimising the total costs, but regulation may, if poorly designed, direct companies to partial optimisation of the costs.

One of the problems in the quality regulation is the time lag between the investments and the effects on the power quality, as has been described earlier. Therefore, additional elements of some kind may be needed to guarantee appropriate quality levels. Ajodhia and Hakvoort (2005) have named three such regulatory elements: (1) the regulator could ensure that companies spend enough money on the quality, (2) the regulator could prescribe and audit companies' asset management process, and (3) the regulator could monitor the condition of the network.

However, all these elements imply more detailed regulation, which in turn would increase the direct costs of regulation, and decrease companies' freedom to choose the best practices. In addition, although the power quality of the network is at an optimal level, the quality for an individual customer may be under the acceptable level. Therefore, in addition to the economic regulation, there could be a need for the supervision of the quality indices of individual customers.

3.5.2. Quality indices

Continuity of supply can be measured by quality indices, such as SAIFI (System Average Interruption Frequency Index), SAIDI (System Average Interruption Duration Index), CAIDI (Customer Average Interruption Duration Index), and MAIFI (Momentary Average Interruption Frequency Index). These indices are defined as shown in Equations (3.7)–(3.10) (IEEE 2004).

$$SAIFI = \frac{\sum Total\ number\ of\ customers\ interrupted}{Total\ number\ of\ customers\ served} \tag{3.7}$$

$$SAIDI = \frac{\sum Customer\ interruption\ durations}{Total\ number\ of\ customers\ served} \tag{3.8}$$

$$CAIDI = \frac{\sum Customer\ interruption\ durations}{Total\ number\ of\ customers\ interrupted} = \frac{SAIDI}{SAIFI} \tag{3.9}$$

$$MAIFI = \frac{\sum Total\ number\ of\ customers\ momentary\ interruptions}{Total\ number\ of\ customers\ served} \tag{3.10}$$

If the system-level indices are based on the number of secondary substations affected by the interruptions, instead of the customer level interruption data, terms T-SAIFI, T-SAIDI, T-CAIDI, and T-MAIFI are used.

As the names of these indices indicate, they reflect the average quality in the network. In an approach of this kind, it is assumed that the inconvenience caused by an outage is equal for every customer. Usually, this is not the case, but the inconvenience and costs of an outage are notably higher for a large industrial plant than for a small household, for example. Therefore, a natural approach would be to include customer-specific values for outages in the quality regulation. However, in the monopoly sector in particular, discrimination of customers should be prevented; this could be interpreted so that outages should be valued equally for every customer, independent of the size or type of the customer. Nevertheless, to maximise the total socio-economic welfare, the different inconveniences caused by an outage for different customers have to be taken into account. Therefore, regulation directs companies to develop the network so that the total loss of welfare that is a result of the imperfect reliability is minimised, if the customer-specific values are used instead of the average interruption indices. In addition, by using interruption costs instead of quality indices, the quality of supply can be defined with a single parameter, which can contain information about short and long interruptions, as well as announced and unannounced interruptions.

Interruption costs can be measured by estimating the direct or indirect costs that are caused by the outage. In the case of an industrial customer, this cost can be due to a loss of production, for instance. However, for a typical residential customer, the inconvenience caused by an outage may be difficult to measure in financial terms. As Kariuki and Allan (1996) have stated, the interruption costs of the residential customers can be estimated either by a preparatory action method (PAM) or by rate-related methods (RRM). In the first of these, the costs of the actions that are needed to alleviate the impacts of the interruption are estimated. Rate-related methods include two approaches: it is either possible to ask the customers' willingness to pay (WTP) for more secure electricity, or alternatively, the customers' willingness to accept (WTA) can be investigated by asking how large a compensation has to be paid in order for the reduced quality to be acceptable. The different costs of the announced and unannounced, as well as short and long interruptions, can also be taken into account in these estimations.

In Finland, the latest extensive study about the outage costs for customer has been published in 2005 (Silvast et al. 2005). The results of this research project have been used as a basis for determining the customer-specific outage cost parameters that can be used in the economic regulation. These parameters are presented in Table 3.1.

Table 3.1. Finnish outage cost parameters (Silvast et al. 2005, Honkapuro et al. 2006c).

Customer type	Unannounced interruption		Announced interruption		High-speed auto-reclose	Delayed auto-reclose
	€/kW	€/kWh	€/kW	€/kWh	€/kW	€/kW
Household	0.36	4.29	0.19	2.21	0.11	0.48
Agriculture	0.45	9.38	0.23	4.80	0.20	0.62
Industry	3.52	24.45	1.38	11.47	2.19	2.87
Public consumption	1.89	15.08	1.33	7.35	1.49	2.34
Service	2.65	29.89	0.22	22.82	1.31	2.44

After the outage cost parameters (€/kW, €/kWh), which are usually referred as parameters A and B, have been determined by the methodology presented above, the interruption costs can be calculated for each interruption type (unannounced, announced, short interruption) by multiplying the non-delivered power and energy by the outage cost parameter of each interruption and customer type, as shown in Equations (3.11)–(3.14).

$$IC_{unannounced} = \sum_{i=0}^{I}\sum_{j=0}^{J} CA_{i,j} * \overline{P}_{i,j} * \left(A_{j,unannounced} + B_{j,unannounced} * t_i\right), \tag{3.11}$$

where

$IC_{\mathrm{unannounced}}$ = interruption costs of the unannounced interruptions

$CA_{\mathrm{i,j}}$ = number of customers in the customer group j affected by the outage i

$\overline{P}_{i,j}$ = average interrupted power of a customer of the customer group j due to the interruption i

$A_{\mathrm{j,unannounced}}$ = outage cost parameter A [€/kW] for the customer group j for unannounced outages

$B_{\mathrm{j,unannounced}}$ = outage cost parameter B [€/kWh] for the customer group j for unannounced outages

t_{i} = interruption time of the outage i

I = number of interruptions during a certain time period

J = number of different customer groups

$$IC_{\boldsymbol{announced}} = \sum_{i=0}^{I}\sum_{j=0}^{J} CA_{\boldsymbol{i,j}} * \overline{P}_{\boldsymbol{i,j}} * \left(A_{\boldsymbol{j,announced}} + B_{\boldsymbol{j,announced}} * t_{\boldsymbol{i}}\right), \tag{3.12}$$

where

$IC_{\mathrm{announced}}$ = interruption costs of the announced interruptions

$A_{\mathrm{j,announced}}$ = outage cost parameter A [€/kW] for the customer group j for announced outages

$B_{\mathrm{j,announced}}$ = outage cost parameter B [€/kWh] for the customer group j for announced outages

$$IC_{High-speedAR} = \sum_{i=0}^{I}\sum_{j=0}^{J} CA_{\boldsymbol{i,j}} * \overline{P}_{\boldsymbol{i,j}} * A_{\boldsymbol{j,High-speedAR}_{i}}, \tag{3.13}$$

where

$IC_{\mathrm{high\text{-}speedAR}}$ = interruption costs of the high-speed auto-recloses

$A_{\mathrm{j,High\text{-}speedAR}}$ = outage cost parameter A [€/kW] for the customer group j for high-speed auto-recloses

$$IC_{delayedAR} = \sum_{i=0}^{I} \sum_{j=0}^{J} CA_{\boldsymbol{i,j}} * \overline{P}_{\boldsymbol{i,j}} * A_{\boldsymbol{j,delayedAR}} \,, \tag{3.14}$$

where

$IC_{\mathrm{delayedAR}}$ = interruption costs of the delayed auto-recloses

$A_{\mathrm{j,delayedAR}}$ = outage cost parameter A [€/kW] for the customer group j for delayed auto-recloses

When considering the cost parameters for the short interruption, that is, a delayed or high-speed auto-reclosing, the amount of such interruption type has to be borne in mind. In Fig. 3.3, the average percentage values of the number of interruptions in rural areas in Finland are presented.

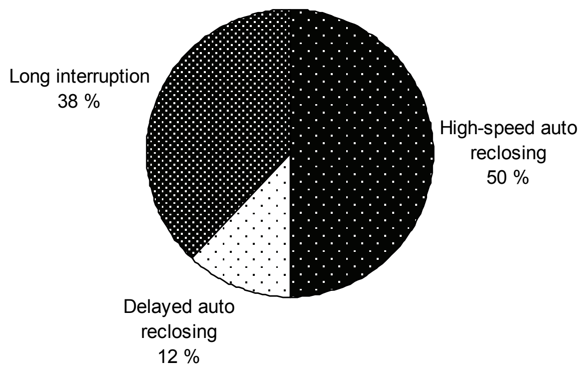

Figure 3.3. Average percentage values of the number of interruptions in a rural area in Finland in 2006 (ET 2007).

A considerable part of interruptions usually consists of short interruptions in the overhead line networks. For instance in rural area networks in Finland, about a half of all the interruptions are high-speed auto-reclosings, as can be seen from Fig. 3.3. Inconveniencies that these interruptions, which last less than one second, cause to a normal domestic customer are usually minimal. However, the same interruption type can be clearly disturbing for the highly automated processes of industrial or agricultural customers. However, even if the unit cost of a short interruption is low, a large amount of those interruptions can lead to significant costs, caused by high-speed auto-recloses. Therefore, regulation may encourage companies to concentrate on reducing the short interruptions, instead of the long interruptions, which is obviously not the desired directing signal. Hence, unwanted directing signals can occur, if this issue is not taken into account in the design of the quality regulation. In practice, this problem can be eased for instance by including a dead-band so that short interruptions affect only after their number is high enough. Another solution could be to consider all the short interruptions during a certain time period, for instance one hour, as one interruption. For example, according to Honkapuro et al. (2006c), the number of high-speed auto-recloses reduces by 39 %, if all such interruptions from the time period of one hour are considered as a single interruption. However, this issue has not received any notable attention yet, most likely because short interruptions are in many cases excluded from quality regulation.

3.5.3. Quality adjustments

The basic idea of quality adjustment is to convert interruption costs, incurred by customers, to costs that actually affect companies' profits. In practice, this aim is achieved by providing companies with a reward for the improved quality and penalise the decreased quality level, as shown in Figure 3.4.

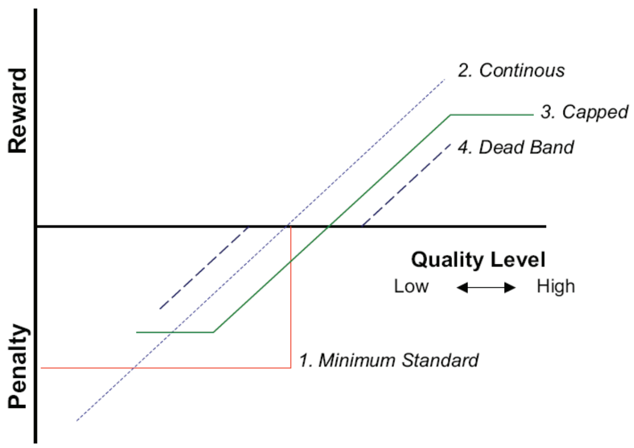

Figure 3.4. Examples of quality adjustment schemes (Ajodhia and Hakvoort 2005).

A quality adjustment can be fixed (scheme 1 in Fig. 3.4) or continuous (scheme 2); further, it can be capped (scheme 3), which means that changes after a certain point do not have an effect on the price adjustment, or it can have a dead-band (scheme 4), so that small changes do not affect the adjustment, as shown by Ajodhia and Hakvoort (2005). Price adjustment is positive, if the quality is better than its reference value, and negative, if the quality is below the reference value. In practice, a quality factor can be a quality index, such as SAIFI or SAIDI, or the total interruption costs of the customers.

Theoretically, this method directs companies towards a socio-economic optimum quality level, if interruption costs and operational and capital costs have a similar effect on the profit of the company, and the actual quality does not affect the reference value for the quality. Or, as Ajodhia and Hakvoort (2005) have stated, if a company is allowed to retain all the social surplus, it will strive for the optimum quality level. In such a situation, the allowed revenue of a company increases because of the quality improvement by the amount that is equal to the decrease in the interruption costs incurred by customers. Therefore, in the economic sense, a distribution company performs such actions (e.g. a network investment or a maintenance task), which decrease the interruption costs of the customers by a higher amount than they increase the operational and capital costs of the company. Hence, the company is encouraged to increase its quality level until it reaches the socio-economic optimum. On the other hand, if the quality level of the company is superoptimal, the company benefits from the cost savings as long as it does not decrease its quality level below the optimal point. Obviously, this assumption holds only if the unit prices of the outages reflect correctly the welfare loss of the customers, which is due to the interruptions. If this is the case, then the welfare of the customers does not depend on the quality level, since an increase or decrease in the allowed revenue of the company, that is, the prices paid by the customers, is adjusted by the same amount that the interruption costs of the customers change.

However, in practice, directing signals may not be theoretically optimal, since the updating of the reference value of the quality may transfer the welfare increase from the company to the customers, or vice versa. In addition, updates in the X-factor or regulatory asset or cost base have such an effect that different cost items, viz. operational, capital, and interruption costs, may have different effects on the profit of the company.

3.5.3.1. Reference value in quality adjustment

A key issue in the implementation of the quality adjustment is to define the reference value, or target level, of quality, with which the actual quality level is compared. The reference value can be based on the company's interruption statistics or on its operational environment. The combination of these two is also possible. A problem in the latter approach, that is, in the definition of the reference value based on the operational environment, is to find appropriate parameters to describe the typical quality level of the company. Indices such as the percentage of forest in the distribution area, climatic conditions, typical depth of the snow during winter or population density, can be considered for describing the operational environment of a company. To guarantee non-discriminatory treatment of companies, all the relevant indices should be included in the definition of the reference value. However, in practice, the availability of data becomes a problem, if all the aforementioned indices have to be collected.

To overcome the difficulties discussed above, concerning the availability of the environmental data, the past outage data of the company can be used as a basis of the reference value of the quality. In that case, the data needed for determining the reference value is the same quality data that is needed to define the quality adjustment. Therefore, additional data collection for determining the reference value is not needed, but the same data will suffice, only its collection has to have begun several years before the quality adjustment can be introduced. However, an approach of this kind may seem unfair from the viewpoint of those companies that have made significant efforts to improve the quality level before the quality adjustment is introduced. That is because these companies do not get any economic gains from the quality improvement they have made, but the target level of the quality is actually higher compared with the companies that have not improved their quality level. This problem can be alleviated by including individual improvement targets in the quality adjustment. These targets require companies to improve their quality towards territorial reference levels, as the case is in Italy (Ajodhia et al. 2006). Obviously, this approach requires defining the territorial reference values, which is as difficult task as the definition of the companies' reference levels. Another approach that improves the benefits of the "early birds" is to include quality in the efficiency evaluation, which is discussed in the next section. Another issue that affects the economic gains of the quality improvements is the updating of the reference value. If the reference value is based on the quality indices of the company and it is updated in the future, company cannot retain all the economic benefits of the quality improvements.

3.5.4. Quality in efficiency benchmarking

In addition to the quality adjustment, incentives for quality improvements can be introduced by including the quality of supply in efficiency evaluation. For instance Giannakis et al. (2005) have stated that it is desirable to integrate service quality and capital expenses in the benchmarking and incentive regulation of the electricity distribution sector. As it is discussed earlier, the major outputs of the distribution company are quantity and quality of delivered energy. However, quality can also be considered as an input, by taking into account that there is a substitute between the quality and other inputs, such as labour or capital, as stated by Coelli et al. (2007). Another justification for treating quality as an input is related to the controllability of that parameter. Although the quality of supply is to some extent dependent on external issues, such as weather conditions and the operational environment, the distribution company has obviously possibilities to affect it by network investments and maintenance works. Therefore, if it is assumed that the distribution company can control the input parameters, and the outputs are outside the company's control, quality can be considered an input.

Similarly as in the case of quality adjustment, the quality of supply can be measured as a quality index, such as SAIDI or SAIFI, or alternatively a company's interruption costs can be used. From the methodological viewpoint, there are two basic methods to include quality as an input of the efficiency evaluation: it can be either a separate parameter, or it can be combined with the capital and operational costs as a total cost parameter. The latter approach assumes naturally that quality is measured as interruption costs. As it has been stated earlier (see section 3.2.1), there are some aspects, which speak for the approach where quality is combined with other input parameters, especially when considering the issue from the directing signals' viewpoint.

3.6. Data collection

According to Coelli et al. (2003, p. 83), costs incurred by the regulated firms in data gathering should be minimised. Nevertheless, it should be borne in mind that the direct costs of the economic regulation are usually clearly smaller than indirect costs, which are a result of the directing signals of the regulation (see e.g. Viljainen 2005, p. 8). Therefore, the cost of the data gathering should not be the only reason to exclude some essential information from the regulatory model. However, in an optimal situation, there would be no such data that would be needed only in the regulation. In other words, to ensure that the gathering of the regulatory data does not incur excessive costs for the distribution companies, all the data needed in the regulation should be such that is also used by the distribution companies in their own activities.

3.6.1. Data availability

At least some part of the cost data needed for efficiency analysis is available directly from the account records of the companies. That is one reason why incentive schemes usually concentrate on the cost efficiency at earlier stages of the regulation, and incentives for quality are introduced at the more mature part of the regulation, as stated above. However, although operational costs can usually be based on the accounting records, collecting the comparable data concerning the capital costs of the companies is a more challenging task, as discussed earlier.

In the case of the power quality data, the data availability usually varies considerably between the companies. Some companies may be interested in the quality issues and voluntarily collect the quality data for their own purposes, while other companies might not start the data collection until the authority orders to do so. However, details of the quality data could differ significantly, if the instructions for data collecting are not uniform. Unambiguous guidelines for data collection are needed for instance to differentiate short and long interruptions. In addition, companies need time to install systems, such as measurement devices and software, which are needed for the systematic collection of the interruption data. If the aim is to collect also the data concerning voltage quality or interruptions in the low voltage networks, the systems required are usually more complicated, and hence more expensive. Furthermore, since quality levels differ significantly between the years, because of the variation in weather conditions, data from a long time period is needed to reflect the typical quality level of a distribution company. Therefore, the collection of the quality data has to be started several years before the data can be used in the regulatory purposes.

3.6.2. Data quality

When considering the practical application of the incentive schemes, one of the most important issues is the data quality. Incentive schemes and regulatory benchmarking can be highly developed, but they can be applied in practice only if the quality of the input data is high enough. If data quality is at a low level, the outcomes of the regulatory calculations cannot be expected to be reliable. Or as Coelli et al. (2003, p. 83) put it, garbage in equals to garbage out.

Although data quality is important in all the elements of the regulation model, its role is of most importance in the efficiency benchmarking, since poor data quality of one company may affect the efficiency scores of the other companies. Therefore, the efficiency score of the company could be higher or lower than it should be only because of the errors in the input data of some other company.

Closely related to the quality of the data is also the quantity of the data; in other words, what is the number of companies included in the benchmarking. In some cases, the number of the benchmarked companies is increased by including companies from other countries in the benchmarking process. The key reason for this is to increase the possibility that the best-practice company is being included in the data set (Coelli et al. 2003, p. 95). Although this international benchmarking might theoretically improve the reliability of the benchmarking results by increasing the number of benchmarked companies, it also has some drawbacks, which may decrease the consistency of the results. The comparability and quality of the data in the international benchmarking may cause difficulties. Coelli et al. (2003, pp. 84–87) name issues such as differences in the tax legislation, wage rates, and inflation between the countries, which weaken the potential of the international comparisons. In addition, Shuttleworth (2005) illustrates that the accuracy of the benchmarking results may decrease, if there is need to add variables to the benchmarking because of international comparisons. Ajodhia et al. (2006) also state that comparisons of the performance data between the countries should be treated with caution, since there might be differences in the definitions and measurements, especially in the case of quality issues. Another method for expanding the data set is the use of panel data, that is, data from a number of years. However, there are also problems in that approach; for instance, data might not be collected on a consistent basis for several years, as reported by Shuttleworth (2005).

3.7. Conclusions on incentive schemes

One of the major objectives of the power sector restructuring has been to increase the efficiency of the industry. In the field of the power distribution, this aim has to be fulfilled by the means of economic regulation because of the lack of the competition. Since the traditional profit regulation does not provide companies with efficiency incentives, regulators are in many cases changing, or have changed, their regulatory models from profit regulation to incentive regulation. However, when companies are provided with efficiency incentives, and the customers cannot choose their distribution company, there is an obvious concern that efficiency gains are achieved by the price of the quality. Therefore, also the quality of supply has to be regulated, especially when companies receive benefits from cutting their costs.

Theoretically, incentives for efficiency gains can be included in the economic regulation by ensuring that a decrease in the costs of the companies leads to an increase in their profits. However, it needs to be ensured that also the customers benefit from the efficiency gains. In practice, efficiency benchmarking has usually an essential role in this process, since it is applied during the determination of the efficiency requirement, the X-factor in RPI-X regulation. Such a factor can be divided into general and individual parts; the general efficiency requirement reflects the productivity increase in the whole industry, while the individual part is determined based on the efficiency potential of the individual company compared with other companies. Sharing of the efficiency gains between the company and the customers is dependent on the updating of the cost base and the X-factor.

Economic regulation of the quality of supply, again, can be done by introducing quality adjustment or including quality in the efficiency evaluation. Quality adjustments increase or decrease the allowed revenue or profit of the company based on the discovered quality of supply. Hence, interruption costs, incurred by the customers, are internalised in the economic decision of the distribution company. A similar effect can be achieved by including quality in the efficiency benchmarking.

However, it should be ensured that companies are allowed to collect sufficient revenues to fulfil the requirements of the regulation, as illustrated by Viljainen (2005, p. 41). For instance, if the improvement in the power quality is expected from the companies, then also funds for the needed network investments should be allowed to be collected from the customers. In addition, it should be noticed that after a certain point, the benefits of stricter price regulation do not outweigh increased costs of the quality regulation, as stated by Ajodhia and Hakvoort (2005). Therefore, efficiency and quality incentives should be balanced so that customers, owners, and employees of the distribution companies and the whole society will benefit from the performance improvements.

4. Regulation in Finland – earlier models

In this chapter, the former regulation models used previously in Finland are described, and some of their practical effects on the distribution companies are analysed. Hence, the chapter presents the regulatory framework, which was the starting point for the regulatory development, and illustrates the real-life effects of the economic regulation in the case-study. At the beginning of the chapter, the business environment and the development of the electricity market restructuring are described. After that, the former Finnish regulation frameworks, first the one used before the year 2005 and next the model applied during the years 2005–2007, are presented. Towards the end of the chapter, the real-life effects of these regulation models are analysed.

The stepwise restructuring process of the power sector started in Finland in 1995. Competition was introduced in the generation and sale of electricity, while distribution and transmission remained in the position of a natural monopoly. In addition, the Energy Market Authority (EMA) was introduced to supervise and promote functioning of the industry. In the early years, only large customers were able to choose their electricity supplier. However, after 1998, also small customers have been free to buy electricity from any supplier they wish.

Large-scale privatisation of the electricity distribution sector has not been seen in Finland, but most of the distribution companies have remained municipally owned after the restructuring process. However, because of the mergers and acquisitions, the number of the distribution companies has decreased from about 110 to about 90 during the last ten years, as can be seen from Fig. 4.1.

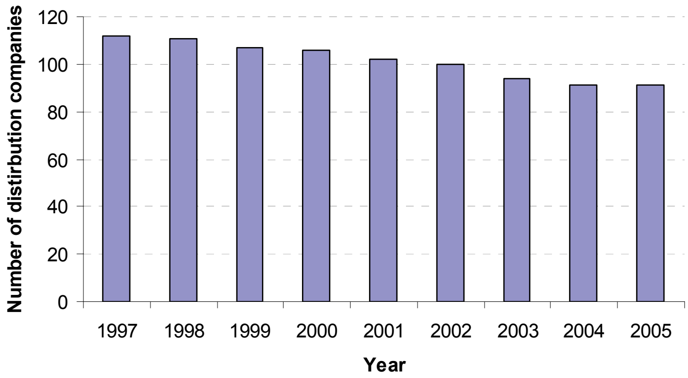

Figure 4.1. Number of distribution companies in Finland.

Development of the method for the regulation of distribution pricing has been going on since the restructuring process begun in 1995. Major steps in this development process have been first decision about the reasonableness of pricing in 1999, which came legally binding in 2000, the introduction of efficiency benchmarking in 2001, implementation of standard compensation scheme for long interruptions in 2003, and the new regulatory models for the first and second regulatory periods, as shown in Fig. 4.2.

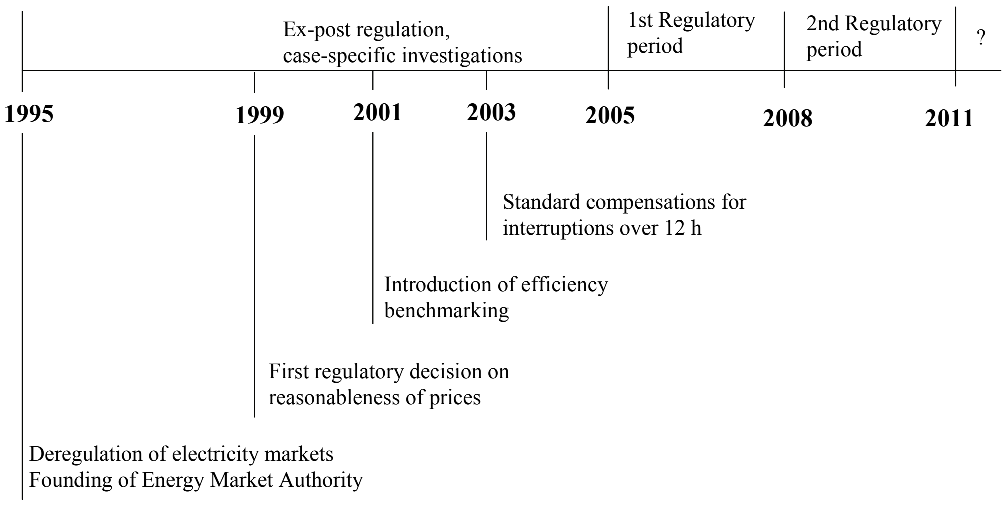

Figure 4.2. Development of the economic regulation of electricity distribution in Finland.

More specific details of the regulation models and an analysis of the development process of the economic regulation are presented in the following parts of the thesis.

4.1. Years 1995–2004 – case-specific regulation

The regulation of the reasonableness of the distribution pricing was ex-post and case-specific between the years 1995–2004. Regulatory investigations were started based on the suspicions of overcharging, usually as a consequence of the complaint of a customer. The regulatory model applied was developed during the first inspections of the distribution pricing. The first decision on the reasonableness of distribution pricing was made in 1999, and it became legally binding in 2000. Since the regulatory interventions were case-specific, most companies experienced only a threat of regulation.

The regulation method was rate-of-return (ROR). The regulatory asset base was the present value of the distribution network, which was calculated based on the repurchase value of the network and its deprecation time and age, as shown in Equation (4.1).

$$NPV = RV * \left(1 - \frac{age}{lifetime}\right), \tag{4.1}$$

where

NPV = net present value of the network

RV = repurchase value of the network

age = average age of the network components

$lifetime$ = technical-econimic lifetime of the network components

Book values were not used in the regulatory calculations, since they may differ significantly from the actual present values of the network. This could be for instance because the companies have chosen their depreciation methodologies so that tax liabilities are minimised or they could have booked investments as operational costs, as clarified by Viljainen (2005, pp. 67–68). Furthermore, because of that, also reasonable depreciation expenses, used in the regulatory calculations, had to be based on some other than accounting value. To ensure that the distribution companies had adequate incentives for investments, the EMA (1999) decided to use three years' average investment costs as an approximation for reasonable depreciation costs.

A simplified illustration of the regulation model used in Finland during the years 1995–2004 is presented in Fig. 4.3.

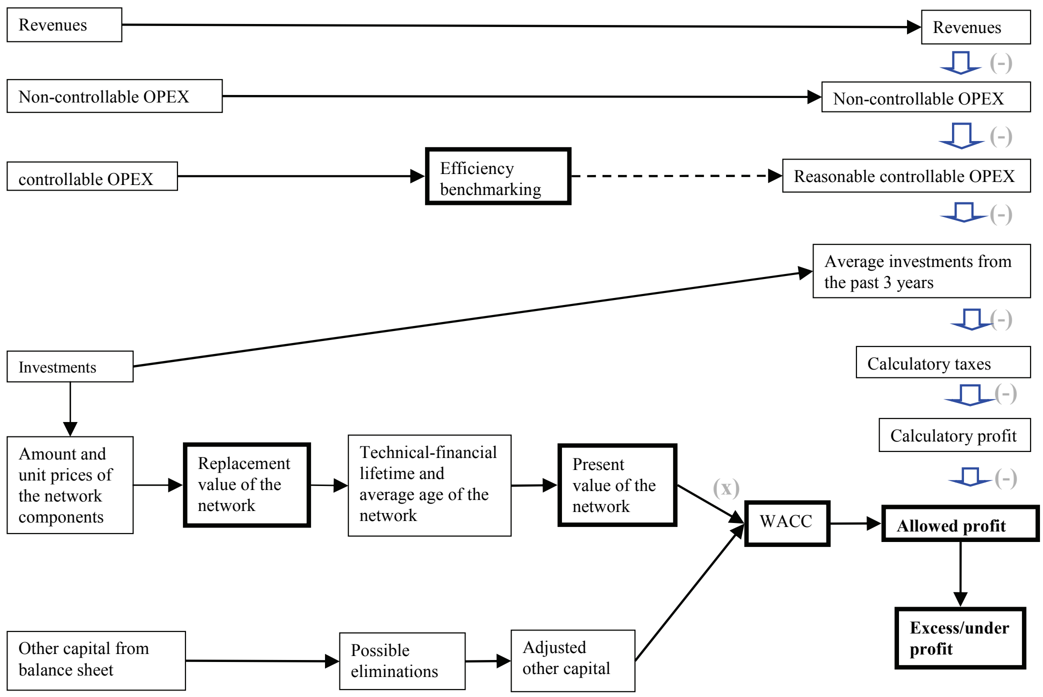

Figure 4.3. Simplified illustration of the regulation model used in Finland between 1999 and 2004.

Reasonable cost of capital was determined by the Weighted Average Cost of Capital (WACC) method, which is shown in Equation (4.2) (EMA 2003).

$$WACC = C_D * (1 - TR) * \frac{D}{D + E} + C_E * \frac{E}{D + E}, \tag{4.2}$$

where

C_{D}	= average cost of loan capital
C_{E}	= reasonable return on equity
TR	= tax rate
D	= amount of loan capital
E	= amount of equity

Reasonable return on equity was determined by the Capital Asset Pricing Model (CAPM), which is presented in Equation (4.3) (EMA 2003).

$$C_E = R_r + \beta_E (R_m - R_r), \tag{4.3}$$

where

C_{E}	= cost of equity
R_{r}	= risk-free interest rate
β_{E}	= beta of equity, describing the risk of the business
R_{m}	= average return in markets
R_{m} - $\mathrm{R_r}$	= risk premium of markets

Risk-free interest rate was the interest of five-year Finnish government bond, beta was 0.3 and risk premium was defined as 5 %. Hence, the cost of equity in the regulatory calculations was the risk-free interest rate added by 1.5 %. The cost of loan capital was the average rate of interests of the enterprise loans in Finland (EMA 2003). The reasonable return on equity and the cost of the loan capital during the years 1997–2004 are presented in Table 4.1.

Table 4.1. Reasonable return on equity and the cost of loan capital during the years 1997–2004 (Viljainen 2005, p. 69).

Year	Reasonable return on equity (including risk supplement) [%]	Cost of loan capital [%]
1997	6.36	5.21
1998	5.80	4.86
1999	5.57	4.51
2000	6.77	5.97
2001	6.04	4.70
2002	5.91	4.32
2003	4.78	3.57
2004	4.75	3.43

4.1.1. Regulatory benchmarking

In the first regulatory decision, evaluation of the efficiency was based on the comparisons of the parameters such as employees per customers or operational costs per delivered energy. The first study concerning efficiency benchmarking in the Finnish electricity distribution sector was the report by Honkatukia and Sulamaa (1999), in which the DEA model with three input and three output parameters was proposed for evaluating the efficiency of the distribution companies. The input parameters of the model were the number of employees, the length of lines, and transformer capacity, while the energy delivered, the number of customers, and the total road length in the distribution area were chosen as output parameters. The method was developed further by Korhonen et al. (2000); see also Korhonen and Syrjänen (2003). In that study, an input-oriented DEA model with variable returns to scale was chosen to be used. The input parameter of the model was that part of the operational costs, which is considered controllable by the distribution company. The output parameters were the value of the delivered energy and the quality of supply, measured as the total interruption time of the customers. In practice, interruption time was included in the model as a non-controllable input parameter, and thus, its influence was similar as if it were a negative output. The parameters describing the operational environment of the companies were the number of customers and the total length of the distribution network. The object function of the DEA model can be presented as shown in Equation (4.4).

$$h_i = \frac{u_1 * energy_i + u_2 * network_i + u_3 * customers_i - v_2 * interruption\,time_i - u_0}{v_1 * OPEX_i}, \quad (4.4)$$

where

h_i	= DEA score of the company i
$energy_i$	= value of the delivered energy of the company i
$network_i$	= total length of the distribution network of the company i
$customers_i$	= number of the customers of the company i
$interruption\ time_i$	= total interruption time of all the customers of the company i
$OPEX_i$	= controllable operational costs of the company i
$u_{1\ldots3}$	= weight of the output parameter
$v_{1\ldots2}$	= weight of the input parameter
u_0	= free variable

The purpose of the benchmarking was to define the reasonable operational costs of a distribution company. The basic idea is that the efficient cost level, evaluated by the DEA, corresponds to the cost level at which the companies have realistic possibilities to operate. However, to ensure that companies do not suffer from potential errors in the benchmarking, the error marginal of 0.1 was added to the efficiency score. Thus, the reasonable operational costs of a distribution company were calculated as shown in Equation (4.5) (EMA 2001).

$$RC_i = (h_i + 0.1) * OPEX_i \quad (4.5)$$

Where

RC_i	= reasonable controllable operational costs of the company i
h_i	= efficiency score of the company i, calculated by the DEA method
$OPEX_i$	= actual controllable operational costs of the company i

In practice, Equation (4.5) means that if the efficiency score of the company is lower than 0.9, its reasonable costs are smaller than the actual costs. Instead, if the efficiency score is above 0.9, the company is granted an efficiency bonus, which is equal to the difference between the reasonable and actual costs. The efficiency scores for the Finnish distribution companies in 2004 are shown in Fig. 4.4.

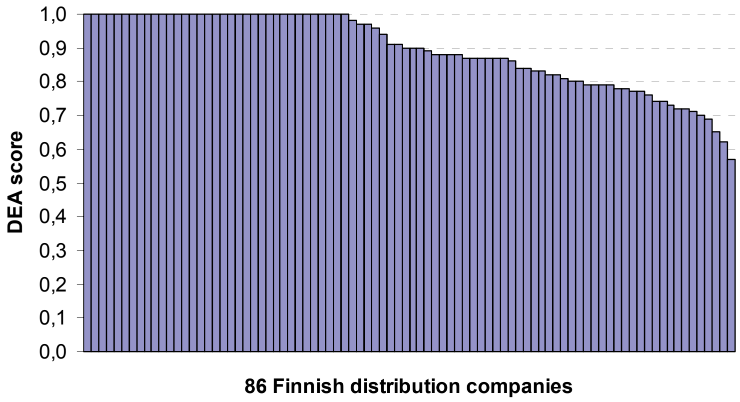

Figure 4.4. DEA scores for 86 Finnish distribution companies calculated with the data of the year 2004. Average 0.89.

For 42 companies, the efficiency score was higher than 0.9, and hence, those companies were granted an efficiency bonus. On the other hand, there were 41 companies, which had an efficiency score lower than 0.9, so according to Equation (4.5), they had to decrease their costs. The efficiency score of the remaining three companies was exactly 0.9.

Controllable operational costs consist of the following items:

- *Materials, accessories, and energy purchases*
- *Increase or decrease in stocks*
- *Staff costs*
- *Rents*
- *Other external services*
- *Other costs*

Production for in-house use is deducted from these costs.

The original idea was to use efficiency evaluation in the determination of the reasonableness of costs from the year 2002 onwards. Since companies were informed about the application methodology of the efficiency score in the year 2001, the EMA decided that efficiency scores before the year 2002 were used only if the company could benefit from them. In practice, this meant that efficiency was included in the regulatory calculations only if the DEA score of the company was higher than 0.9. However, this was actually the only way that the efficiency scores were used. In 2003, the EMA (2003) decided not to introduce new elements in the regulatory model, since the need for greater restructuring of the regulation framework was in sight because of the new European Commission Directive (2003/54/EC). Therefore, the implementation of the efficiency score in the regulatory calculations remained the same also after the year 2002, which meant that efficiency score was taken into account only for those companies that attained the efficiency score higher than 0.9.

However, efficiency scores were computed and published annually for every company, which provided companies an indirect incentive for efficiency improvements. In addition, although companies were not punished for inefficiency, they could achieve an efficiency bonus if the efficiency score was high enough. Therefore, inefficient companies could achieve economic benefit if they were able to improve their efficiency scores.

4.1.2. Role of power quality

Before the year 2005, power quality was included in the economic regulation as a part of efficiency evaluation, since the total interruption time of the customers was an input parameter of the efficiency benchmarking. However, this approach provided quite indistinct incentives for quality improvements, mostly because of two reasons. First, the application of the efficiency scores was such that the efficiency had an effect on the reasonable returns only for those companies that achieved an efficiency score higher than 0.9. Secondly, because of the varying factor weights in the DEA, the effect of the interruption time on the efficiency score was difficult to predict.

However, although the effects of quality through efficiency benchmarking were unclear, quality indices were gathered and published, which can be seen as an indirect quality regulation, described in section 3.5. Furthermore, it is typical in Finland that the same corporation operates in both business areas, viz. the electricity distribution and the sale of electricity. Therefore, the spill-over effect encourages distribution companies to keep the quality of supply at an adequate level.

A new quality instrument was introduced in 2003, when the standard compensation scheme was set up. This method was developed after the large storms in 2001 and 2002. It guaranteed a compensation for the customers, who suffered an interruption longer than 12 hours. The compensation is based on the length of the interruption and the annual distribution bill, as shown in Table 4.2.

Table 4.2. Standard compensations for long interruptions (Electricity Market Act 386/1995).

Length of the interruption	Compensation (per cent of annual distribution bill)
12–24 hours	10 %
24–72 hours	25 %
72–120 hours	50 %
Over 120 hours	100 % (maximum compensation is 700 euros)

However, standard compensations have an effect only in the case of long interruptions, and hence, the system does not encourage decreasing the amount or length of the interruptions that do not last over 12 hours.

4.1.3. Discussion about the regulatory model

The first regulation model for electricity distribution sector was developed during the first inspection on the reasonableness of pricing. In that time, the business environment was new for all players, the regulatory agency had just been founded, and there were plenty of new issues and challenges to be tackled. Therefore, it is obvious that the first regulatory model was only a starting point, and plenty of development work was needed, not least since the directing signals of the regulatory model were quite problematic.

Incentives for investments are typically strong in the ROR regulation, as stated earlier in this thesis. In this particular regulatory model, three years' investment costs were used as reasonable depreciation costs, while the efficiency evaluation focused solely on the operational costs. Hence, the distribution company was able to collect all the capital expenses of any network investment from customers within three years' time. In addition, if a network investment decreased the interruption time or operational costs, an efficiency bonus could be achieved. Therefore, incentives for even overinvestments were strong in this regulatory model, as for instance Viljainen (2005, pp. 73–74) has illustrated.

Efficiency benchmarking included in the ex-post regulation was inconvenient for companies, since they were informed about the desired cost levels only afterwards. Hence, companies did not know beforehand the level of the operational costs, which they were allowed to. In practice, this problem was eased, because the efficiency score affected only if the distribution company had benefit of it. However, this led to a situation, where already efficient companies but also inefficient companies, the efficiency scores of which were notably smaller than 0.9, did not benefit from the efficiency improvements. For some efficient companies, there were even incentives to increase their operational costs, because the efficiency bonus they were entitled to was dependent on the actual operational costs.

Another problem in this regulatory model was the role of power quality. Theoretically, the model provided incentives to reduce the interruption time, since it was included in the efficiency evaluation. However, other interruption indices were not included, and the regulation focused thereby solely on the interruption time. In addition, the effect of the interruption time on the efficiency score and reasonable incomes were quite unclear, as mentioned previously. In addition to the efficiency benchmarking, there was also standard compensations that the companies had to pay for the customers for interruptions longer than 12 hours. However, standard compensations were categorised as a non-controllable operational cost, and thus they were treated as pass-through cost items in the regulatory calculations. In practice, this meant that although companies had to pay compensations for the customers, who had suffered an interruption longer than 12 hours, distribution prices could be increased so that companies were allowed to increase their revenues by the amount of the paid compensations. However, since the length of the regulation period was only one year, an increase in the distribution prices had to be carried out during the same year that compensations were paid. Obviously, this is difficult, if the outages occur at end of the year. In addition, increasing the distribution prices after the long interruptions may have unfavourable effects on the public image of the company.

4.2. Years 2005–2007 – the first regulatory period

The European Commission Directive (2003/54/EC) states that the regulator has to approve beforehand at least the methodologies that are used to calculate the distribution tariffs. In addition, the regulator has to give a decision on the complaints within four months. To comply with the Directive, the Finnish regulatory model had to be restructured. The major modification to the previous model was the introduction of the three-year regulatory period, and some changes towards ex-ante regulation. In the previous model, decisions on the reasonableness of pricing were made individually for each examined year, while in the new model one decision was made concerning the whole three years' period. In practice, this means that overcharging in one year can be compensated by undercharging in the other year of the same period, as described by the EMA (2004). In addition, the overcharge of the whole period must be returned to the customers in the next period by decreased prices. Correspondingly, a company can collect higher prices in the second period, if it undercharged customers in the first period (EMA 2004).

The ROR method remained the basic principle of the regulation; however, there were major changes in other parts of the regulation model. One of the most significant changes was the determination of the reasonable depreciation costs. Instead of the past investment costs, reasonable depreciations were based on the straight-line depreciations, which are calculated from the repurchase value of the network. Technical-economic lifetimes of the components, used in the depreciation calculations, indicate the companies' opinion about the time that a network component is actually in the network before replacement. Companies can choose these lifetimes freely, but they have to be inside the pre-defined boundaries, which are presented for the most common components in Table 4.3.

Table 4.3. Technical-economic lifetimes used in the regulatory calculations (EMA 2007a).

Component group		Technical-economic lifetime [a]
Distribution substation	Pole-mounted	25…40
	Pad-mounted	30…40
Distribution transformers		30…40
Overhead lines	Medium-voltage	30…45
	Low-voltage	25…40
Underground cables	Low- and medium-voltage	30…45
Primary substations	Transformers, busbars, and switchgears	30…45
Energy meters		15…25
Software		5…10

These lifetimes, presented in the table above, are based on the surveys and interviews of the distribution companies (Partanen et al. 2002).

Another important modification in the model, compared with the previous one, was the calculation of the value of the network. The repurchase value of the network assets was calculated based on the unit costs and the amount of the network components. The unit costs of each component are standard costs, set by the regulator, and they are based on the national statistics about the prices of the network components. In the first year of the regulatory period, the present value of the network was calculated based on the repurchase value, lifetime, and the age of the network, similarly as in the previous model. For the following years, the present value was adjusted by annual investments and depreciations, as well as changes in the Building Cost Index (BCI), as shown in Equation (4.6) (EMA 2004).

$$NPV_t = \left(\frac{BCI_{t-1}}{BCI_{t-2}}\right) * \left(NPV_{t-1} - SLD_{t-1} + Investments_{t-1}\right), \tag{4.6}$$

where

NPV_t = net present value of the network in year t

BCI_t = building cost index in the second quarter of year t

SLD_t = Straight-line depreciation in year t

$Investments_t$ = network investments in year t calculated by standard costs

Allowed return was determined based on the repurchase value of the network and WACC per cent. Changes in that part of the regulation concerned the cost of loan capital and the capital structure of the companies. The cost of loan capital was based on the risk-free interest rate and a premium of 0.6 per cent, instead of the average interest rates of the business loans. In addition, the capital structure was fixed for every company assuming that 30 per cent of total capital is debt and 70 per cent is shareholder's equity. Reasonable returns on capital for the years 2005–2007 are presented in Table 4.4. Return is different for municipal utilities and limited companies, because of their different corporate tax rules.

Table 4.4. Reasonable return on capital during years 2005–2007 (EMA 2007e).

Year	Reasonable return on capital (municipal utilities) [%]	Reasonable return on capital (limited companies) [%]
2005	6.07	5.57
2006	5.15	4.73
2007	5.76	5.29

Straight-line depreciations were calculated based on the repurchase value of the network components and their technical-economic lifetimes, as shown in Equation (4.7) (EMA 2004).

$$SLD = \frac{RV}{lifetime}, \tag{4.7}$$

where

SLD = straight-line depreciation of the distribution network

RV = repurchase value of all network components

$Lifetime$ = weighted average of the technical-economic lifetimes of the network components

A simplified illustration of the regulation model is shown in Fig. 4.5.

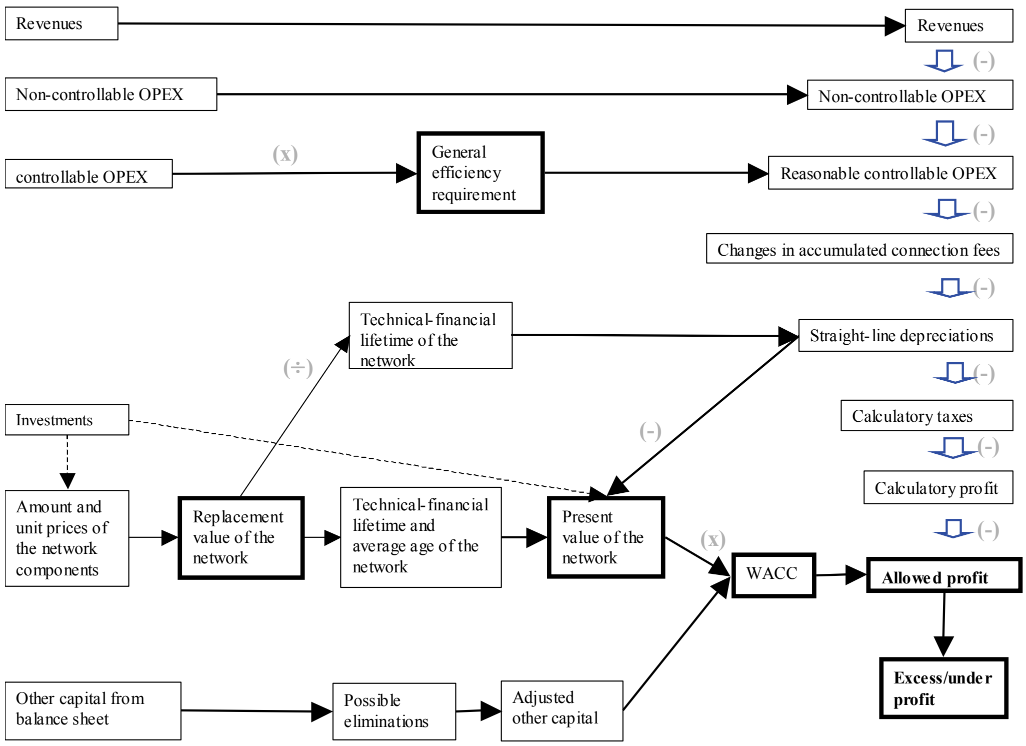

Figure 4.5. Simplified illustration of the regulation model used in Finland during the years 2005–2007.

4.2.1. Efficiency requirement

Because of the development needs in the efficiency benchmarking, an individual efficiency requirement was not included in the new model at the first regulatory period, but there was only a general efficiency requirement, which was equal for every company and focused on the controllable operational costs. This efficiency requirement was based on the frontier shift in the DEA during years 1999–2002. It was measured by the Malmquist index component that describes the movement of the efficient frontier, and the same DEA model as previously was used. Hence, the general efficiency requirement reflects the efficiency improvement of the most efficient companies, and it is assumed that the less efficient companies can improve their productivity for at least the same percentage as the most efficient ones have done (EMA 2004).

The annual frontier shift during the years 1999–2002 was found to be 2.2 per cent. This figure is inflation-adjusted, and hence the effect of inflation had to be deducted from it to generate the efficiency requirement, which allows the change in the value of the money. Therefore, the annual efficiency requirement, focusing on the controllable operational costs of the distribution company was 1.3 per cent. However, changes in the extent of the operation, such as the increase in the network length, might affect the typical operational costs of the distribution company. To ensure that the reasonable operational costs of the company remain sufficient even if for instance the length of the network increases, these costs were adjusted by the annual changes in the network volume (NV), which is calculated by Equation (4.8) (EMA 2004).

$$NV = 4.2 * OHL_{hv} + 23 * UGC_{hv} + 1 * OHL_{mv} + 0.9 * UGC_{mv} + 0.53 * LL_{lv} + 0.025 * CA\,, \qquad (4.8)$$

where

NV = network volume

OHL_{hv} = length of high-voltage (110 kV) overhead lines

UGC_{hv} = length of high-voltage (110 kV) underground cables

OHL_{mv} = length of medium-voltage (6-70 kV) overhead lines

UGC_{mv} = length of medium-voltage (6-70 kV) underground cables

LL_{lv} = length of low-voltage (0.4 kV) lines

CA = number of customers

Annual efficiency requirement, including the changes in the network volume, was calculated by Equation (4.9) (EMA 2004).

$$ER = \left(\frac{101.3}{100 + \Delta NV} - 1 \right) * 100\%\,, \qquad (4.9)$$

where

ER = annual efficiency requirement

ΔNV = annual percentage change in the network volume

4.2.2. Role of power quality

In practice, power quality did not have any economic effects in the regulatory model of the first period. The standard compensation system, described in section 4.1.2, was similar in the new regulatory model, but also treating of the standard compensation cost remained the same, that is, these costs were treated as uncontrolled operational costs. However, quality statistics were collected from the distribution companies, and the data was published. Hence, the indirect quality regulation was continuing. In addition, the Energy Market Authority had announced that it may intervene in the quality of supply, if it finds that the quality is deteriorating or it is inferior to the quality of other similar companies (EMA 2004). In addition to that, until the year 2007, there had been uncertainty about how the collected quality data will be used in the future. Therefore, although there was not direct economic regulation of the quality of supply, a threat of quality regulation was present, at least in theory.

4.2.2.1. Development in the compilation of the interruption statistics

The Energy Market Authority has compiled interruption statistics of the Finnish distribution companies from the year 1996 onwards. Until 2004, two interruption indices were collected, viz. the number and length of the interruptions at the secondary substation level (T-SAIFI and T-SAIDI). However, in these indices, it is assumed that all the secondary substations within the distribution company are homogeneous. Furthermore, these indices do not provide any information about the interrupted power. Therefore, the Energy Market Authority decided to renew the compilation of the interruption statistics. Eight new interruption indices, which are gathered from all the distribution companies from the year 2005, are described in Table 4.5 (Kivikko et al. 2005a, 2005b).

Table 4.5. New interruption indices compiled by the Energy Market Authority (Kivikko et al. 2005a).

	Interruption index	Energy-weighting
1	Customers' average annual interruption time caused by unexpected interruptions	Yes
2	Customers' average annual number of interruption caused by unexpected interruptions	Yes
3	Customers' average annual interruption time caused by planned interruptions	Yes
4	Customers' average annual number of interruption caused by planned interruptions	Yes
5	Customers' average annual number of interruption caused by delayed auto-reclosings	Yes
6	Customers' average annual number of interruption caused by high-speed auto-reclosings	Yes
7	Number of unexpected interruptions in low-voltage network	No
8	Number of unexpected interruptions in medium-voltage network	No

In addition to these new interruption indices, also old ones, T-SAIFI and T-SAIDI, are still collected. Indices 1–6 in Table 4.5 are weighted by the annual energy of the interrupted customer. Interruption indices are divided into unexpected and planned ones, as well as short, that is, delayed or high-speed auto-reclosings, and long ones. Therefore, the annual interruption cost of the distribution company can be calculated far more accurately with these new indices than with T-SAIFI and T-SAIDI. However, there are still development needs in the interruption statistics. Calculation of the interruption costs would be more accurate, if the interruption indices, presented in Table 4.5, were divided into customer types. In addition, statistics about the interruptions in the low voltage network are still inaccurate, since information about the fault in the low voltage network is usually brought to the attention of the operational staff only by the customers. However, this situation will most probably be improved as automatic meter reading (AMR) becomes more common.

4.2.3. Discussion about the regulatory model

Major changes in the regulatory model had been the three years' regulatory period, instead of the earlier annual calculations, and the use of straight-line depreciations instead of the past investment costs as an estimate for reasonable depreciations. The three years' regulatory period increased the stability of the business to some extent. However, three years is a relatively short time in such a business as electricity distribution, where asset lifetimes are several decades.

Since there was no information available about the upcoming regulatory model until the year 2007, the uncertainty of the future made the decision-making of the distribution companies difficult. Although the regulation model was based on the principles of ROR regulation, the regulator determined also the allowed operational and depreciation costs. Therefore, the regulator actually defined the allowed revenue of the company.

Although there were still incentives for overcapitalisation, these incentives were not as strong as in the previous model because of the change in the determination of the reasonable depreciation. In the previous model, the average of the three years investment costs were used as reasonable depreciation costs, as illustrated above. In the new model, straight-line deprecations, calculated from the repurchase value of the network, were used as an indicator of the reasonable deprecation costs. Hence, companies could not collect investment costs from the customers during three years as before, but the effect of the investment on the reasonable depreciations was distributed to the whole lifetime of the component. In addition, replacement investments did not affect the straight-line depreciations, since only an extension investment increased the repurchase value of the network. In theory, all investments were still beneficial, since they increased the regulatory asset base. However, since the quality of supply did not have any economic consequences, companies could not achieve additional profits by network investments, which increased the quality level. Although efficiency benchmarking was not included in the regulation, companies could gain benefits by decreasing their operational costs, since they were granted to retain all the cost savings during the regulatory period. Since the allowed profits were calculated based on the standard unit costs of each component group, companies could achieve higher profits also if their costs for building the network were lower than the standard costs.

4.3. Impacts of regulation

The effects of regulation on the regulated companies can be estimated by studying how issues such as the price of electricity and the quality of supply, as well as investment and cost levels, have changed during the years. Changes in these issues can be compared with the development of the regulatory model to find out if there are any correlations between the regulation model and the practical impacts. However, in addition to the economic regulation, there are obviously many other issues that affect the prices, quality, and costs of a distribution company. For instance, the requirements of the asset owners partly decide whether the price of distribution is close to the maximum price allowed by the regulator.

4.3.1. Prices

Some impacts of the economic regulation can be estimated by studying the development of prices. Figure 4.6 presents the development of distribution price levels for household and mid-sized industrial customers between 1997 and 2007. The prices are adjusted by changes in the consumer price index.

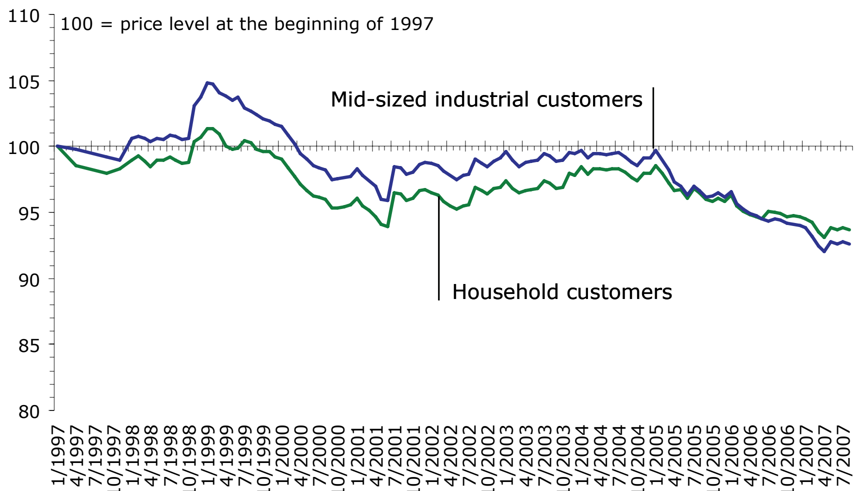

Figure 4.6. Development of distribution price levels (without taxes) for household and mid-sized industrial customers between 1997 and 2007. The prices are adjusted by changes in the consumer price index (EMA 2007b).

It can be seen that during 1997 and at the beginning of 1998, the prices have remained quite stable. The first major changes in the distribution prices occurred late in 1998 and at the beginning of 1999; first, the prices increased rapidly, and then from 1999 to 2001, there was a steady decrease in the prices. From 2001 to 2004, there was a slightly increasing trend in the prices, and since the beginning of 2005, the prices have been decreasing.

According to the EMA (2000), the rapid increase in the distribution prices in late 1998 and at the beginning of 1999 is a consequence of changes in the pricing of the national grid transmission, which took place in November 1998. However, in February 1999, the Finnish regulator made the first decision on the reasonableness of pricing (EMA 1999). Although the decision was not yet legally binding because of an appeal that had been lodged against it to the Supreme Administrative Court, it had effects on the distribution prices, as also the EMA (2000) has stated. Prices started to fall as the companies were now conscious that the regulator might inspect the reasonableness of their pricing, and the principles used in these inspections were spelled out for the first time.

While the distribution prices decreased quite rapidly after the first pricing decision, they began to increase slightly after the year 2001. The first reactions to the regulation model could have been oversized, and hence, after a few years, when companies were getting familiar with the regulation model, they could adjust their prices to better correspond with the demands of the regulation model. On the other hand, regulatory decisions were such that they obligated to change the pricing in the future, but refunds for the customers were not needed. Therefore, the consequences of the possible overcharging were minor.

At the beginning of 2005, the new regulation model came into force. For the companies, this meant that there was not only a threat of the regulatory intervention, as earlier, but the pricing of every company was investigated. This change has had clear effects on the prices of electricity, as companies have lowered their prices after the beginning of the year 2005, which can be seen from Fig. 4.6. However, according to the EMA (2007c), for the most of the companies, the actual profit has been smaller than the allowed one in the year 2005. When comparing the sum of the profit shortfalls and surpluses and revenues of all distribution companies, we can see that the total revenue of companies could have been 6 per cent higher than it was in 2005. In other words, average price of the distribution could have been 6 per cent higher, if all the companies have gathered the maximum allowed revenue. Therefore, price deductions could have been oversized. In addition, the value of network assets, and hence the allowed profits and depreciation costs, are adjusted by the changes in the building cost index, which have been increasing faster than the consumer price index, as shown in Fig. 4.7.

Therefore, the allowed revenues of the companies have most probably been increasing faster than the consumer price index.

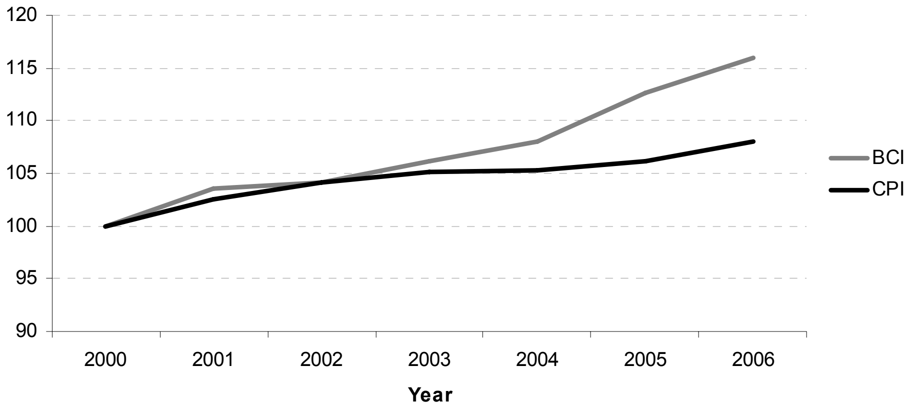

Figure 4.7. Building Cost Index (BCI) and Consumer Price Index (CPI) between 2000 and 2006 (the value of both indices in 2000 is 100) (EMA 2007a, Statistics Finland 2007).

Based on the findings presented above, it can be said that regulation, especially the introduction of the new model at the beginning of 2005, has had an effect on the distribution prices. However, it seems that companies tend to overreact to the changes in the model by decreasing the prices more than what is needed.

4.3.2. Quality of supply

Some correlations between the pricing decisions and the development steps in the regulatory model have been discovered, as shown in the previous section. These could be seen as a consequence of the fact that there have been legally binding decisions about the reasonableness of the pricing of the distribution companies. However, the regulation of the quality of supply has mostly been carried out by indirect regulation, and there have not been strong incentives for quality improvements or penalties for the deterioration of quality. However, the regulation model has been based on the ROR regulation, which theoretically provides incentives for overinvestment and superoptimal quality levels (see section 3.1.1). Therefore, if the theoretical directing signals of the ROR regulation realise, it could be assumed that the distribution companies have improved their quality levels, even without any quality-specific incentives. However, the theory does not always go hand in hand with practice, as can be seen from Fig. 4.8., where the development trend of the total interruption time of the customers in Finland during the years 1973–2006 is shown.

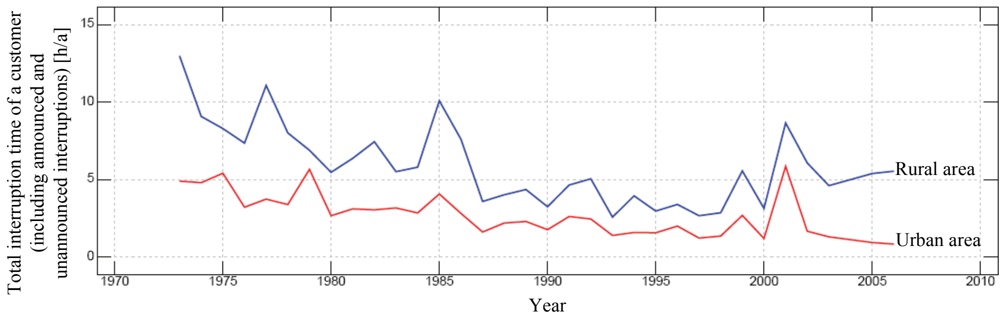

Figure 4.8. Total interruption time of the customers in Finland between 1973 and 2006 (ET 2007).

As it can be seen from Fig. 4.8., interruption time in rural and urban areas has been decreasing steadily from the 1970s to the 1990s. In those years, regulation has mainly been based on the public ownership, where electric utilities were largely owned by the municipalities, and the aim of such utilities has usually been to provide good quality with low prices for local inhabitants (Viljainen 2005, p. 53). In addition, during those years, the technology has developed, and at the same time, demands of the customers have been continuously increasing. Therefore, companies have been increasing their quality levels, even without any formal regulation.

After the mid-1990s, simultaneously as the restructuring process of the industry took place, interruption times in the rural area have been increasing. Based on this finding, it seems that the theory of ROR regulation providing companies with incentives for too high quality levels seems to conflict with the practice in this case. However, at the same time, there have been incentives for decreasing the operational expenses, which, alongside of the investment levels, affect the quality of supply.

There are obviously various other issues than the restructuring process and quality regulation that affect the observed quality levels of the distribution companies. For instance, the compilation of the interruption statistics has developed, and because of that, it could seem that the number and duration of interruptions increase, even if the actual quality levels have not changed. In addition, weather conditions obviously affect the quality levels; for instance, there have been some large storms at the beginning of the new century, which can be seen also from Fig. 4.8. Again, there seems to be a slight decrease in the interruption time in urban areas during the 2000s.

4.3.3. Investments

As it is stated above, in theory, ROR regulation provides companies with incentives for even overinvestments. In the regulation model used in Finland prior to year 2005, the three years' average of the investments was used as reasonable depreciation costs. Hence, incentives for overinvestments were particularly strong, since companies were able to finance their investments with almost direct cash flow. However, investment levels of the Finnish distribution companies have been quite low, when comparing annual network investments with straight-line depreciations, as shown in Fig. 4.9. Straight-line depreciations have been calculated based on the company-specific technical-economic lifetimes of the network components. These lifetimes have been chosen by companies themselves, and thus it can be assumed that the straight-line depreciations reflect the companies' view about the annual investment needs.

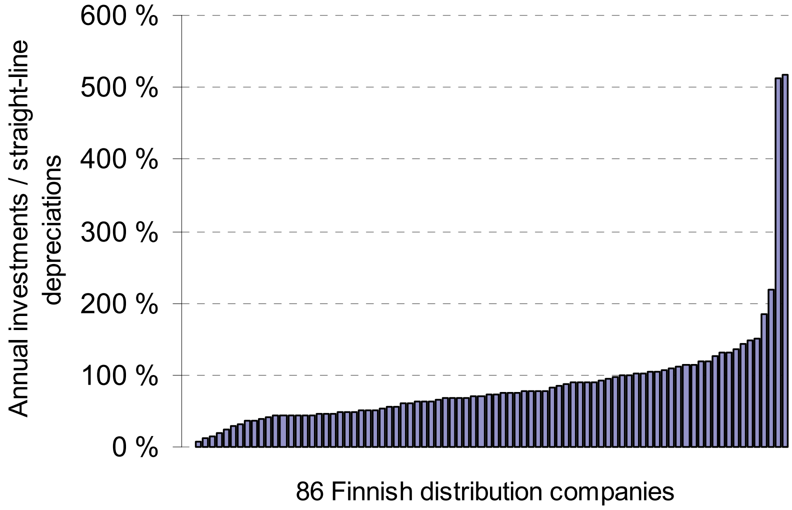

Figure 4.9. Average investments of 86 Finnish distribution companies during the years 2002–2004 compared with straight-line depreciations, average value 86 %, median 73 % (Honkapuro et al. 2006c).

The figure above shows that for the majority of companies, investments have been smaller than straight-line depreciations. The two highest bars on the right-hand side of Fig. 4.9. are significantly higher than the actual network investments, since there have been re-arrangements in the network ownerships of those companies, which have had effects on the investment costs. Although investment levels have been quite low, there has been an increasing trend in the annual network investments, as shown in Fig. 4.10. The investments related to the corporate acquisitions are not excluded from these figures, and hence the investment levels and their annual variations may be higher than the actual network investments. In addition to electricity distribution companies, this figure includes also the investments of the regional grid companies and the national grid company. The information of all these companies is included to ensure that possible changes in the ownership of the networks between these companies do not affect the results.

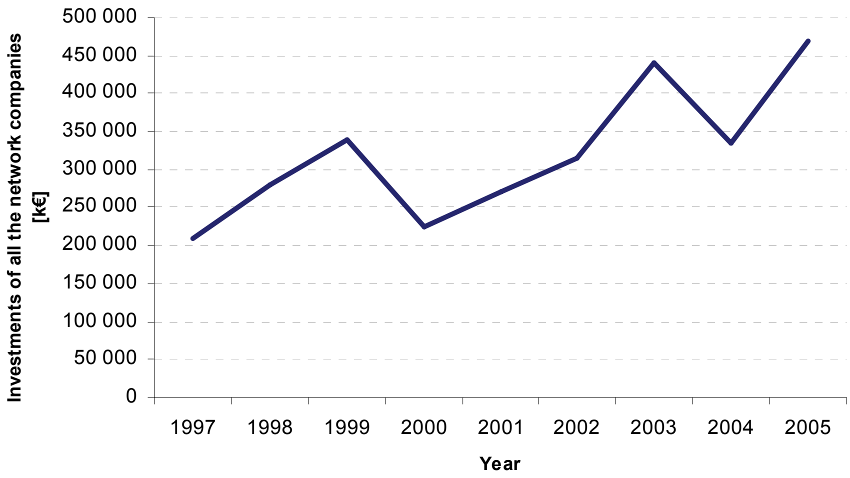

Figure 4.10. Network investments of all the Finnish network companies, including distribution companies, regional distribution companies, and the national grid company during the years 1997–2005. Costs have been adjusted to the price levels of the year 2005 by the changes in the consumer price index.

It seems that although there have been strong incentives for investments, companies have not followed the directing signals of the regulation, but the investment levels have been quite low. Companies could have postponed their investments because of the uncertainty of the development of the regulation model. For instance, there have been discussions about the role of capital costs in the Finnish regulation model and the efficiency benchmarking for several years (see e.g. Korhonen et al. 2000, Partanen et al. 2002, Partanen et al. 2004, and Honkapuro et al. 2006c). In addition, Viljainen (2005, p. 75) has found three explanations for the moderate behaviour of the distribution companies. These are: poor understanding of the regulatory model, absence of a stable business environment, and the ownership structure of the distribution companies, that is, the companies are mainly owned by municipalities, which protects customers from the monopolistic behaviour to some extent. Furthermore, Kinnunen (2006) has found that the uncertainty about the applied regulatory practices has affected the investment behaviour of the distribution companies. However, increasing investment levels could be seen as a sign that the insecurity of the regulatory effects is decreasing. In addition, the introduction of the new regulation model, which includes more ex-ante elements and a regulatory period of three years increased the predictability of the regulatory effects to some extent.

4.3.4. Operational costs

The total operational costs of the Finnish network companies, including distribution and regional companies and the national transmission company, are presented in Fig. 4.11. The costs are adjusted to the price level of the year 2005 by changes in the consumer price index.

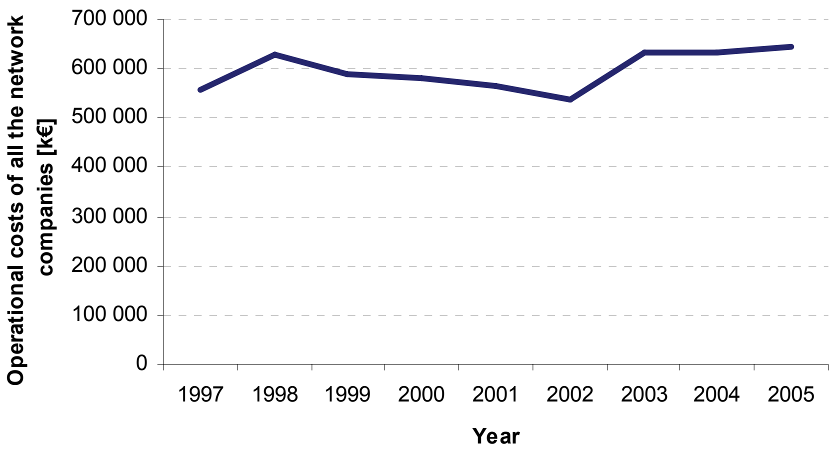

Figure 4.11. Operational costs of all the Finnish network companies, including distribution companies, regional distribution companies, and the national grid company for the years 1997–2005. The costs have been adjusted to the price level of the year 2005 by changes in the consumer price index.

As illustrated in the figure above, the operational costs have been decreasing continuously between the years 1998–2002. There have been stepwise increases in the costs between the years 1997 and 1998, and similarly between the years 2002 and 2003. These are most probably due to changes in the accounting instructions. After the year 2004, operational costs of the companies have been slightly increasing. Changes in the operational costs are in line with the directing signals of the regulation, at least to some extent. Although it was in 2001, when the regulator published the guidelines for the efficiency assessments in the regulatory calculations (EMA 2001), there had already been studies on the efficiency benchmarking before (c.f. Honkatukia and Sulamaa (1999)). Therefore, companies could have reacted to these signals about the efficiency requirements by decreasing their operational costs. However, network investments have been continuously increasing between 2000 and 2003 (see Fig. 4.10). Therefore, there may also have been trade-offs between operational and capital expenses during that period. Nevertheless, in 2003, the regulator decided that efficiency scores are taken into account in the regulatory calculations only if it is beneficial for the company (EMA 2003). This provided a clear signal for the companies that it was not necessary to reduce the operational costs. It seems that the development trend of the operational costs is in line with this signal.

4.4. Conclusions on the previous regulatory models in Finland

The restructuring of the power sector started in Finland in 1995. That year, the first step in the development of the regulatory model for the distribution sector was made, since the regulator received the first complaint about the reasonableness of the distribution pricing. The stepwise development of the regulatory model has continued ever since; the first regulatory decision was made in 1999, and it came legally binding in 2000. The first introduce of the regulatory benchmarking took place in 2001, and in 2003, a standard compensation scheme for long interruptions was introduced. Year 2005 brought significant changes to economic regulation, as the new model with three years' regulatory period and more ex-ante elements were introduced. In addition to modifications in the model, one major principle was also changed: calculations about the reasonableness of pricing were made for every company, instead of the former case-specific regulatory interventions. The major features of the former regulation models used in Finland are presented in Table 4.6.

Table 4.6. Major features of the former Finnish regulatory models.

Time period	Major features of regulation and benchmarking
1995 – 2004 (Case specific regulatory interventions)	• Allowed profit = Present value of the network * WACC • Reasonable depreciation costs = average of the 3 years' investments • OPEX as controlled input and interruption time as non-controlled input in DEA benchmarking • Bonus for efficient companies, no penalties for inefficiency
2005 – 2007 (First regulatory period)	• Allowed profit = Present value of the network * WACC • Reasonable depreciation costs = straight-line depreciations (= repurchase value / lifetime) • Determination of the network value based on the standard unit costs and lifetimes of the components. Lifetimes are chosen by the companies inside the pre-defined boundaries. • Reasonable OPEX based on the historical values and general efficiency requirement

Based on the directing signals of the Finnish regulation models, there have been strong incentives for investments. Nevertheless, the investment levels of the distribution companies have been quite low. This is most probably a consequence of the uncertainty of the regulatory development, which could have led to the postponing of the investments. However, investment levels have been increasing during the recent years, which could be seen as a sign that such insecurity is decreasing. In addition to the investment levels, the impacts of the regulation can be found by analysing the changes in the prices levels, interruption indices, and operational costs. The most definite impacts can be seen in the distribution prices, as a clear correlation between the development steps of the regulation and changes in the prices have been detected. However, it seems that companies tend to overreact to the regulatory changes.

Although the new regulation model, introduced in 2005, brought up some improvements, there were still plenty of development needs. The efficiency benchmarking was not included in the model during the first regulatory period (the years 2005–2007), since the role of the power quality and the capital costs, as well as the treatment of outlier companies, had to be reconsidered. These development needs and the further development process are described in detail in the next chapter.

5. Development of regulatory benchmarking

In order to provide companies with incentives to design their networks and business processes from the viewpoint of the total socio-economical welfare, it is necessary to analyse the directing signals of the regulation and benchmarking during the development process. Hence, developing the methodology for analysing the directing signals of the regulatory benchmarking has been one objective of this thesis. In order to apply such methodology in practice during the development of the regulatory benchmarking, it had to be implemented in an efficient software tool. The developed methodology and software tool are presented in the first section of this chapter. Since the methodology is implemented in practice during the development of the Finnish benchmarking model, the development needs and research questions concerning the former benchmarking model are presented in the second section of this chapter. The development process of the Finnish regulatory benchmarking constitutes the latter part of this chapter.

5.1. Tool for analysing the directing signals of the regulatory benchmarking

The measurement of the performance may direct companies, even if it does not have any economic effects. For instance, if the regulator calculates and publishes efficiency scores, companies may tend to improve their efficiencies in order to avoid the bad public image caused by the possible insufficient efficiency. However, when the measured performance has an effect on the outcome of the regulatory calculations, the incentives for efficiency improvements are stronger, since the improvements concerning the measured parameters have an effect on the allowed incomes.

The major directing signals of the efficiency benchmarking for the network investment are illustrated in Fig. 5.1. The figure shows the basic relations between the network investment and allowed incomes. These signals obviously depend on the regulation model, benchmarking parameters, role of the benchmarking in the regulatory framework, and possible other incentive mechanisms, such as quality adjustment. In this theoretical illustration, it is assumed that operational costs, capital costs, and the cost of non-delivered energy are the parameters of the efficiency benchmarking, and benchmarking has a direct effect on the allowed incomes. In addition, the cost of non-delivered energy and the value of the network assets are assumed to affect the allowed incomes.

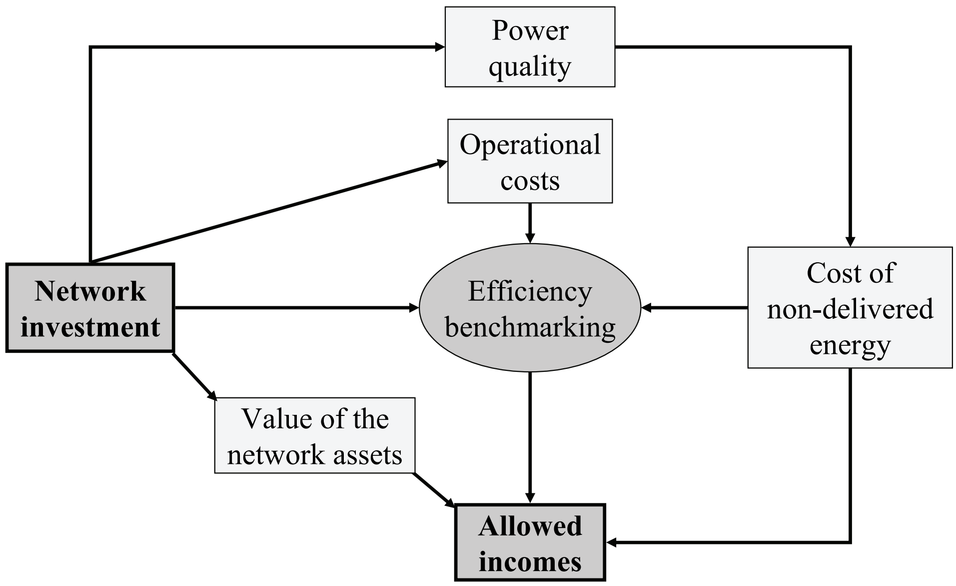

Figure 5.1. Basic relationships between the network investment and regulatory allowed incomes.

Actual directing signals of the regulatory benchmarking can be found by analysing the economic effects of the input parameters of the benchmarking. In practice, there are two steps in this analysis. First, by running a sensitivity analysis, it is analysed how the changes in the magnitude of a benchmarking parameter affect the efficiency score. At the second stage, the economic effects of a benchmarking parameter are analysed based on the sensitivity and the effect of the efficiency score in the regulatory framework. By this process, the marginal price for each benchmarking parameter can be found. In addition to the effects of the benchmarking, the analysed parameters can also affect the allowed incomes in other ways, that is, either directly (for instance the value of the asset base in ROR regulation) or through an incentive mechanism (e.g. a quality adjustment). In this analysis methodology, all these effects are taken into account simultaneously to find the total regulatory effects of the input parameters. This process is illustrated in Fig 5.2. The development needs of the benchmarking and regulation models can be found by such an analysis, and similarly, possible development options can be tested.

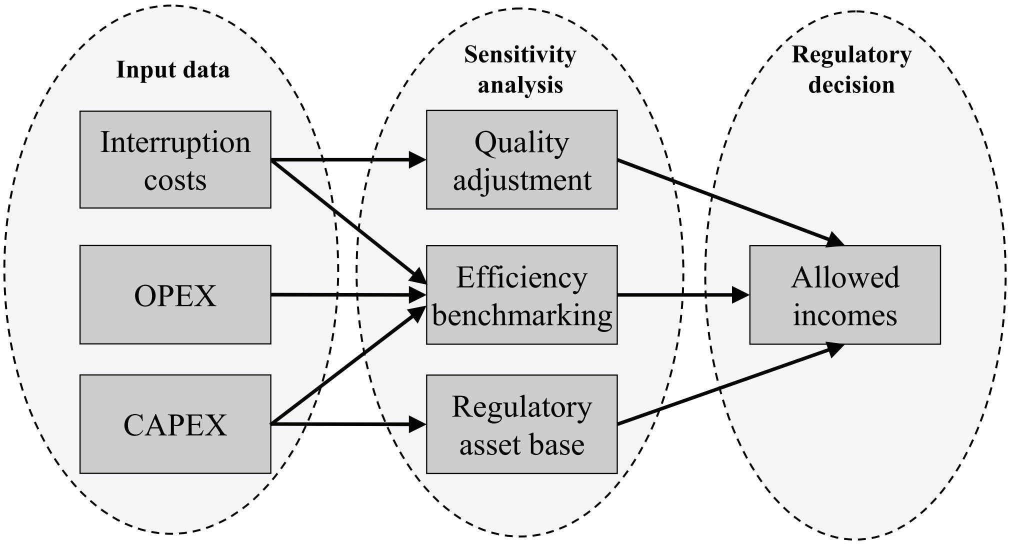

Figure 5.2. Methodology for analysing the directing signals of the economic regulation.

In order to implement this methodology in practice, a software tool was developed, as described in Honkapuro et al. (2006a) and Honkapuro (2002). The requirements for such a software tool are that it has to be capable of analysing the regulatory effects of the changes in the input data for all the companies in the data set. In addition, it has to be able to analyse the regulatory effect of a single parameter, as well as the effects of a network investment, where multiple parameters are changed simultaneously. Furthermore, simulations concerning both a singe company and all the companies are needed. Finally, in order to analyse multiple different models and different investment cases, simulations have to be efficient.

The basic idea of the software tool is to calculate the directing signals of the benchmarking by running simulations, where the input data is changed automatically by a user-defined way, and economic effects of these changes are calculated. One or more parameters can be changed simultaneously for one or all companies. In addition, changes can be made for efficient companies only to find out how the efficiency improvement of the peer companies affect the incomes of the other companies. In this practical implementation, the DEA method is used as efficiency benchmarking methodology. However, similar methodology can also be used with other benchmarking methods. Furthermore, the weight restrictions of the DEA model, described in section 2.2.1, can be applied during these analyses. Weights can be restricted by absolute weight restrictions, relative restrictions of weights, or restrictions of the virtual outputs or inputs. Regulatory effects can be analysed for an individual company, or the average effects of the data variation for all the companies can be computed. The basic principle of the software is illustrated in the flowchart in Fig. 5.3.

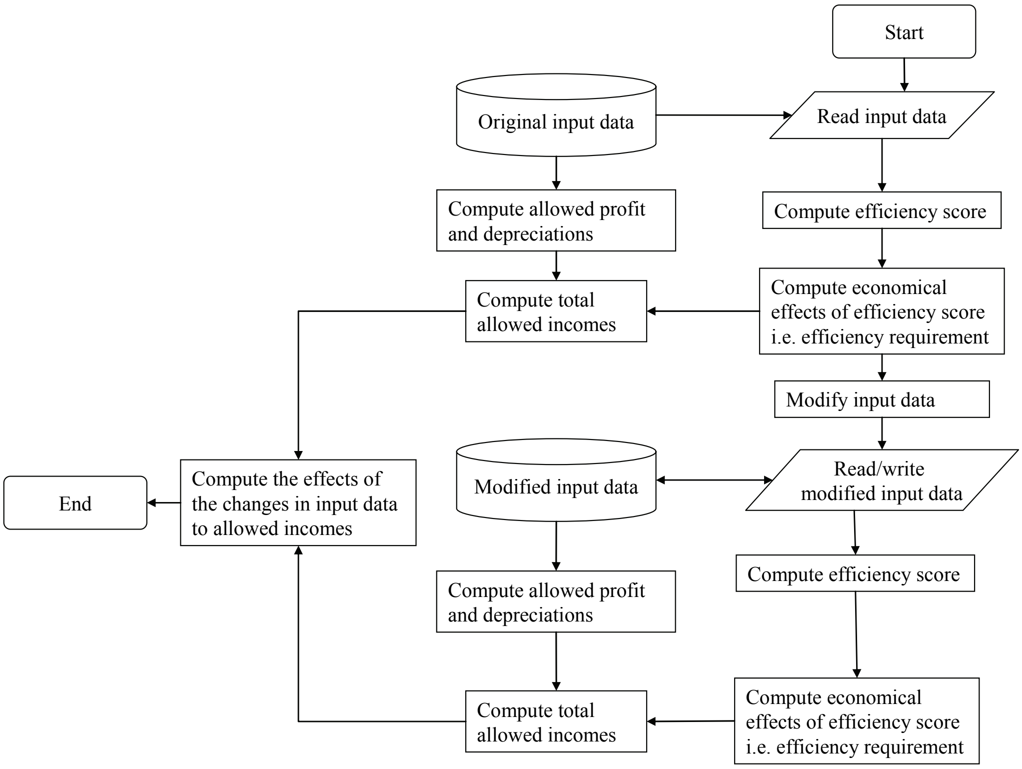

Figure 5.3. Flowchart of the tool for analysing the directing signals.

Computation of the allowed incomes, in the flowchart of Fig. 5.3, includes the economic effects of the benchmarking as well as other regulatory effects of the input data, such as the effects of the regulatory asset base and the effects of the quality adjustment. The process can be adjusted to correspond to the regulatory framework. In addition, it is possible to analyse the subresults of the process, such as sensitivities of the efficiency scores. This tool is applied, for instance, during the analysis presented in the latter part of this thesis.

5.2. Development needs of the regulatory benchmarking

Although the Finnish regulation model had been developing during the years, there remained still certain research questions and development needs, especially in the regulatory benchmarking. These key development issues, as well as proposals for the development of the model, have been found by analysing the directing signals of the regulation and benchmarking for the regulated companies. The main development concerns in the benchmarking were the role of capital costs, the role of quality, and the treatment of outlier companies. The discovered development needs are considered as sub research questions in this thesis, which all together constitute a response for one of the objectives of the thesis, that is, to implement the above-described development methodology in practice.

The most relevant issues in the regulatory benchmarking are: (1) parameter selection, (2) selection of the benchmarking methodology, and (3) application of the results of the benchmarking in the regulatory calculations. Hence, the research questions concerning the development of the benchmarking were found inside these categories.

When considering the directing signals, highly significant benchmarking parameters are power quality and capital costs, since the incentives for network investments and quality improvements are mostly dependent on these parameters. Therefore, the first research question was to analyse the role of the power quality in the efficiency benchmarking. The objective was to analyse the directing signals of the model, where interruption time is a non-controllable input parameter in the benchmarking, and to find whether these directing signals can be improved.

In addition to the power quality, the role of capital costs in the benchmarking had to be developed. Hence, the second research question was to determine the most suitable indicator of the capital costs and an appropriate method for including these costs in the benchmarking process. Since the regulation was based on the ROR methodology, and efficiency benchmarking in the former regulatory framework focused on the operational costs, strong incentives for even overinvestments were provided. Furthermore, companies benefit from the trade-offs between the operational and capital costs, which affected for instance the profitability of the outsourcing and the optimal maintenance strategy, that is, choosing between the maintenance operation and replacement investment. However, including capital costs in the benchmarking process may provide companies with incentives to strive for short-term efficiency gains by neglecting even the necessary investments. Hence, the objective was to find the methodology that provides companies with incentives to minimise the total costs of the electricity distribution, including operational, capital, and interruption costs, during the whole lifetime of the network, but which does not prevent the necessary network investments.

During the development process, the mathematical benchmarking models have been taken as they are, and the DEA model has been taken as the basis of the analysis. Although the development of the mathematical benchmarking methods was not carried out, the methodological development was made by considering the effects of the returns-to-scale assumptions. This issue is of particular relevance, since it has effects on the profitability of the mergers and efficiency incentives of the outlier companies. Hence, the third research question was to evaluate the returns-to-scale assumptions from the viewpoint of the directing signals.

The final economic effects of the benchmarking, and thereby the marginal price of the benchmarked parameters depend on the role of the benchmarking in the regulatory framework. Hence, also the effects of the application the benchmarking results into the regulatory calculations were analysed.

5.3. Power quality

In the previous Finnish benchmarking model, used before the year 2005, the quality was measured as interruption time, which was a non-controlled input parameter. The directing signals of the power quality in the Finnish benchmarking model have been studied comprehensively by Lassila et al. (2002, 2003a, 2005a, and 2005b). These studies show that the marginal price of the interruption varies significantly between the companies, if the interruption time is a non-controlled input parameter in the DEA benchmarking; this is because of the varying weights of the DEA. Such a price of interruptions can be illustrated in practice by studying how the efficiency score change when the interruption time is changed, and calculating the economic effects of the efficiency variation. This is illustrated in Fig. 5.4, where the sensitivity of the efficiency score for the changes in the interruption time is determined for each Finnish distribution company. In this case, the sensitivity refers to the amount that efficiency score changes, when the interruption time is changed by one per cent (Lassila et al. 2002). Percentage values of the efficiency scores are used in this figure, so that efficiency scores vary between 0 and 100 %.

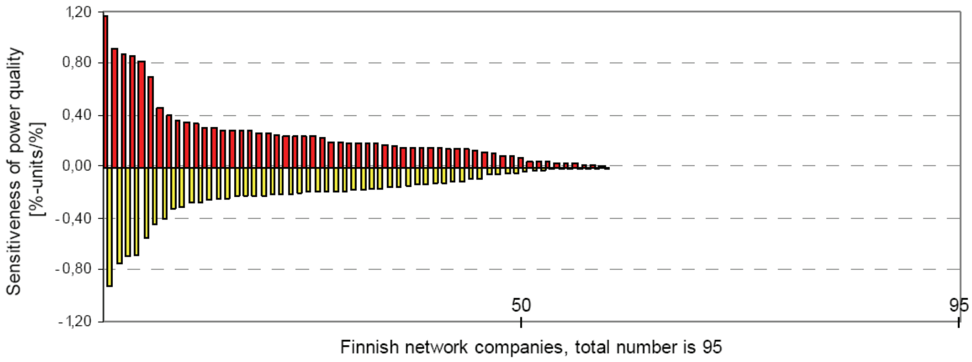

Figure 5.4. Sensitivity of the power quality in the previous Finnish DEA benchmarking. The upper bars present the increase in the efficiency score, when the interruption time is decreased by 1 %, whereas the lower bars indicate the decrease in the efficiency score that is due to a 1 % increase in the interruption time (Lassila et al. 2002).

When the efficiency score has a direct effect on the allowed incomes of the company, as has been the case for instance in Finland (see section 4.1.1), the actual marginal price for the input and output parameters of the benchmarking can be defined. However, efficiency scores were used in that regulation model only for those companies, which benefit from it. Hence, such an economic effect of the interruption time did not cover all the companies, but the incentive mechanism was similar to the one illustrated here only for the companies, the efficiency score of which was between 0.9 and 1.0. According to Lassila et al. (2002), the price of the interruption in the regulatory model used in Finland before the year 2005 can be defined based on the change of the efficiency score that is due to the change in the interruption time (i.e. sensitivity of the interruption time) and operational costs of the company, as presented in Equation (5.1).

$$p_{\text{interruption time}} = \frac{\Delta h}{\Delta interruption\ time} * OPEX\,, \tag{5.1}$$

where

$p_{\text{interruption time}}$	= marginal price of the interruption time
$\Delta interruption\ time$	= change in the interruption time
Δh	= corresponding change in the efficiency score
$OPEX$	= operational costs of the company

As it can be seen from Fig. 5.4, the sensitivity of the interruption time varies significantly between the companies. Therefore, we may assume that also the marginal price of the interruption will vary substantially. According to Lassila et al. (2002), the marginal price of the interruption time of the Finnish distribution companies varied between 0 and 223 €/customer,h, calculated with the input data from the year 1999, as shown in Fig. 5.5. For almost 40 companies the price of the interruption is 0.

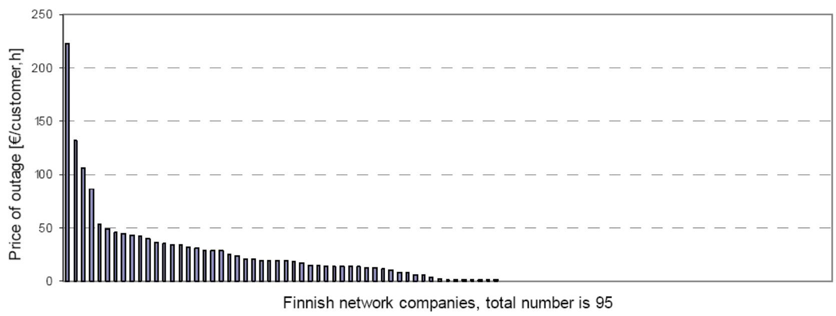

Figure 5.5. Prices of outages for the Finnish electricity distribution companies based on the benchmarking and regulation model used before year 2005 (Lassila et al. 2002).

The directing signals of such a regulation model, where the marginal price of the outage varies substantially, are obviously unclear, especially since these prices varied significantly between the years. The annual variation of the outage prices is illustrated in Fig. 5.6., where the change in the price of the outage between 2000 and 2001 are presented.

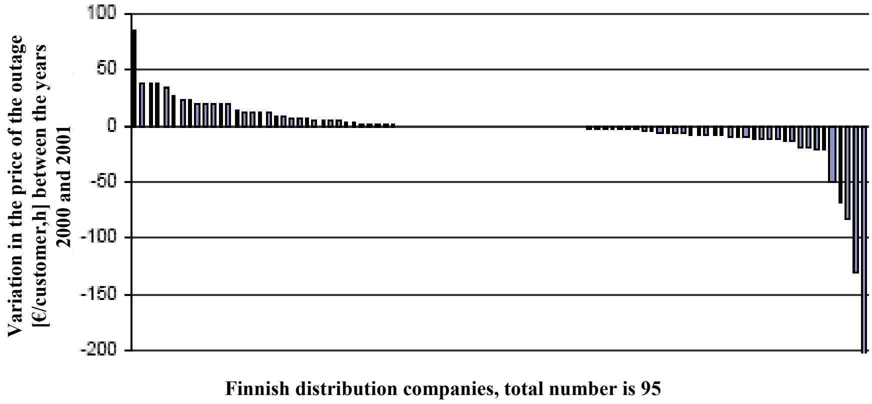

Figure 5.6. Variation in the price of the outage between years 2000 and 2001 (Lassila et al. 2003b).

Because of this variation, companies could not foresee the economic effects of the quality improvements, and hence the directing signals were unclear. Furthermore, a shortcoming of the model was also that power quality was measured as interruption time, which does not provide complete information about the quality level of the company. Since the variation in the marginal prices is a consequence of the varying weights of the DEA model, replacing the interruption time with interruption costs does not improve the directing signals of the benchmarking. Furthermore, the weight restrictions of the DEA did not solve the problem either, as it is shown by Lassila et al. (2003a).

However, such a model is also problematic when considering the nature of its shadow prices. In the measurement of the technical efficiency, the shadow price of an input parameter reflects the potential trade-offs between the input parameters, as it has been demonstrated for instance by Coelli et al. (2007). For instance, if the costs and interruption time are two separate input parameters in the benchmarking model, it is assumed that if the costs increase, interruption time should decrease by certain amount, if all the outputs remain stable, in order to maintain the same level of efficiency. The shadow price of the interruption time reflects in this case the relationship between the cost increase and the decrease of the interruption time, and it is based on the perceived production mixes of the peer group. Hence, shadow prices reflect, at least theoretically, technological production possibilities, that is, feasible inputs and outputs mixes. However, when considering the objectives of the regulation, companies should be provided with incentives for maximising the total socio-economical welfare. As it has been discussed above, quality is optimal from the socio-economical perspective, if the marginal benefits of the quality improvements are equal to the costs of these quality improvements. Hence, to ensure that directing signals of the regulation are in line with its objectives, the shadow price of the interruptions in the benchmarking model should be based on the welfare losses of the customer that are due to an outage, instead of the estimated production possibilities.

Hence, the most suitable solution to overcome the described problems was to measure the power quality as interruption costs, where the number and duration of the interruptions can be taken into account, and interruptions can be divided both into long and short ones, and into announced and unannounced interruptions. These interruption types are multiplied with the corresponding outage cost parameters, which reflect the costs incurred by the customer because of such an interruption. In addition, it is possible to take different outage costs of the different customer types into account in such an approach, if the interruption data are divided between customer types. These interruption costs are combined with operational costs as one input parameter. In such a case, the interruption costs of the customers have an equal effect on the efficiency score as the operational costs of the company. Hence, companies are provided with incentives to perform such actions, where the increase in the costs of the company is smaller than the decrease in the interruption costs of the customers. The object function of the developed model can be presented as shown in Equation (5.2) (Lassila et al. 2003a).

$$h_i = \frac{u_1 * energy_i + u_2 * network_i + u_3 * customers_i - u_0}{v_1 * \left(OPEX_i + IC_i\right)}, \qquad (5.2)$$

where

h_i = DEA score of the company i

$energy_i$ = value of the delivered energy of the company i

$network_i$ = total length of the distribution network of the company i

$customers_i$ = number of the customers of the company i

$OPEX_i$ = controllable operational costs of the company i

IC_i = interruption costs of the company i

$u_{1...3}$ = weight of the output parameter

v_1 = weight of the input parameter

u_0 = free variable

Interruption costs can be calculated as illustrated in section 3.5.2.

In the developed model, variations in the marginal price of the interruptions are significantly lower than in the model, where quality is a separate parameter. In Fig. 5.7., the price of outage in developed model is presented for every Finnish distribution company.

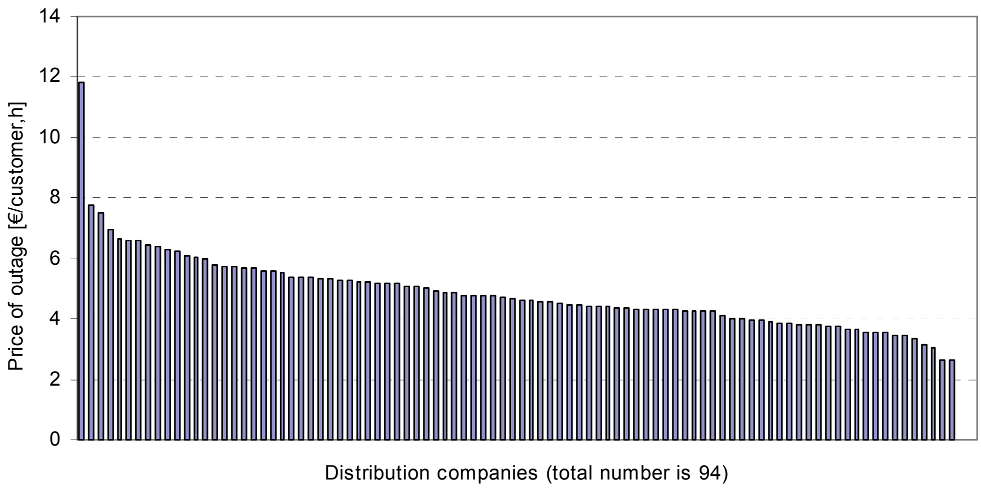

Figure 5.7. Prices of outages in the model, where operational costs and interruption costs are compared as a single input parameter (Lassila et al. 2003a).

However, although this solution developed the benchmarking model so that the directing signals for the quality were improved, capital costs were not included in the benchmarking model, which led to distorted directing signals. Hence, the role of the capital costs in the benchmarking will be considered in the next section.

5.4. Capital costs

Capital costs have not been included in the previous Finnish benchmarking model. Such a benchmarking model, focusing solely on the operational costs, combined with ROR regulation, directs companies to seek trade-offs between OPEX and CAPEX. Hence, companies can achieve efficiency gains by choosing a replacement investment instead of maintenance action, or by booking a maintenance operation as an investment in an unclear situation. In other words, excluding capital costs from benchmarking process creates incentives for partial optimisation. To ensure that regulation directs companies to optimise their total costs, the capital costs have to be a part of the benchmarking process.

Capital costs can be included in the efficiency benchmarking as physical quantities or monetary values, as it has been illustrated in section 3.3. In addition, if monetary values are used, they can be based on the annual investment costs, or capital costs can be measured as depreciations. Furthermore, depreciations can be based on accounting records, or they can be determined from the value of the network assets. All these alternatives have their own advantages and drawbacks, when considering their use in the regulatory benchmarking. In this case, two different approaches are compared: including annual investment costs in the efficiency benchmarking, or using straight-line depreciations, based on the repurchase value of the network. When considering the principle differences of the investment and deprecation costs, it is obvious that depreciation reflects the past investments, while annual investment costs are those that are actually spent at present. Hence, also the directing signals of these two approaches are different.

One significant difference between these two values lies in their annual variations. This is obvious, since the value of the network assets remains quite stable between the years, while investments in the electricity distribution are usually quite lumpy. This difference can be seen from Figs. 5.8 and 5.9, where the annual variation of the investment costs and straight-line depreciations of the Finnish distribution companies are presented. It should be noticed that the scale of the y-axis is different in these two figures.

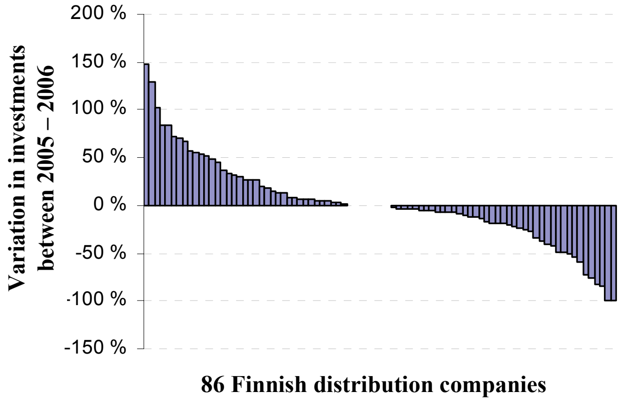

Figure 5.8. Variation in the investment costs of 86 Finnish distribution companies between 2005 and 2006 (Honkapuro et al. 2006c).

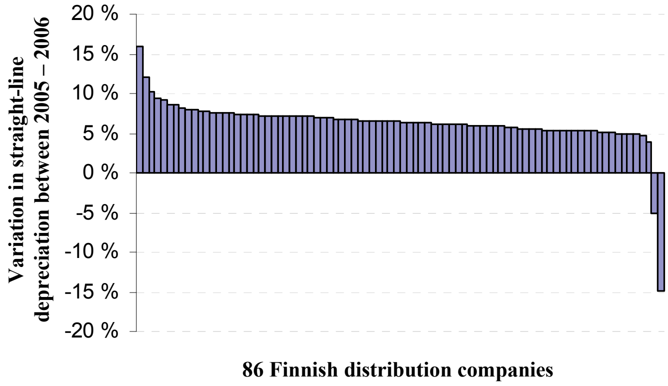

Figure 5.9. Variation in the straight-line depreciations of 86 Finnish distribution companies between 2005 and 2006 (Honkapuro et al. 2006c).

Most of the variation in the straight-line depreciations is due to the fact that the repurchase value of the network, which is used as a basis of the straight-line depreciations, is adjusted by the change in the building cost index, which was 4.2 % between 2005 and 2006. Hence, the increase in the straight-line depreciations has been quite similar for most of the companies. However, even without the index adjustment in the asset value, straight-line depreciations tend to be increasing annually. As it can be seen from the figure above, almost every company's straight-line depreciation has been increasing over 5 per cent. This is because such depreciation can only be decreased by dismantling some part of the network or by rebuilding the network by using less expensive components and/or network structures. Dismantling the network is seldom needed, and further, rebuilding of the network usually takes several decades, if it is done in a cost-efficient way. Consequently, the companies' opportunities to decrease the straight-line depreciations in the short-term are quite limited. This is obviously problematic, if these depreciations are included in the efficiency benchmarking, which is used to derive efficiency requirements for a few years' regulatory period. However, this issue can be taken into account when deriving the efficiency requirement from the results of the benchmarking.

Annual network investments are more controllable by the distribution company than the straight-line depreciations. However, including those in the efficiency benchmarking is also problematic. First, there is significant annual variation in the investment costs, as it has been illustrated above. However, this issue can be overcome by using an average value of several years in the benchmarking. Second, there is a problem concerning the directing signals: if the annual investment costs are a part of the regulatory benchmarking, companies may adopt an idea to increase their efficiency in the short term by neglecting the network investments. Obviously, behaviour of this kind may lead for instance to problems in the quality of supply in the long term. Such a directing signal is discussed next by an example of a network investment.

Let us consider an example that a network company improves its reliability of supply by building new back-up lines. Investment costs of the lines are 500 k€, the depreciation time will be 40 years, and they are assumed to decrease annual interruption costs by 40 k€. If we compare the investment costs and achieved savings in the interruption costs, we find this investment beneficial. The interest-free payback time of the investment is 13 years, and the payback time calculated by 5 per cent interest rate is 20 years. However, the regulatory effects of the investment depend on the role of the capital costs in the efficiency benchmarking. Relevant initial data about the example company are presented in Table 5.1.

Table 5.1. Initial data about the example company.

Annual straight-line depreciations	2000 k€/a
Average annual investments	2000 k€/a
Average annual operational costs	2000 k€/a
Average annual interruption costs	1000 k€/a
Initial efficiency score	0.9 (= 90 %)

If we assume that there are no other changes than the effects of the example investment, and the input data of the reference companies remain stable, the relative change in the efficiency score can be determined based on the relative change in the input parameter. Hence, a new efficiency score can be calculated as presented in Equation (5.3)

$$h_1 = h_0 * \frac{x_0}{x_1}, \tag{5.3}$$

where

h_0 = initial efficiency score

h_1 = new efficiency score

x_0 = initial input parameter

x_1 = new input parameter

Let us consider the effects of the example investment to the efficiency score of the company in two different benchmarking models. In the first case, the single input parameter of the benchmarking is the sum of the annual operational costs, interruption costs, and straight-line depreciations. In the second case, the single input parameter is otherwise similar but the depreciations are replaced by 5 year's average of the investment costs. In the latter case, the investment costs affect the efficiency score only during a five years' period, while the depreciations remain the same for the whole lifetime of the component. Table 5.2 presents the effects of the example investment on the efficiency score. Both the immediate effect and the effect after the five-year period are presented.

Table 5.2. Effects of the example investment on the efficiency score.

Input parameter of the benchmarking	Immediate effect on the efficiency score [% unit]	Effect on the efficiency score after 5 years [% unit]
A) Operational costs + interruption costs + straight-line depreciations	+0.50 % unit	+0.50 % unit
B) Operational costs + interruption costs + five years' average of investment costs	-1.07 % unit	+0.73 % unit

As it can be seen from the table above, this beneficial investment can have a negative effect on the efficiency score of the company, if the model B is used, where investment costs are included in the benchmarking model as a five years' average. On the other hand, the positive effect of the investment on the efficiency score after five years is stronger in the model B than in the model A. In the model A, where straight-line depreciations are used as an indicator of capital costs, the positive effect of this example investment is constant during the whole lifetime of the investment. In this case, the cumulative effect of the investment is same in both cases, but the effect of the investment is negative during the first five years in the model B. In such a method, an investment has short-term negative effects, if its payback-time is longer than five years. This is in many cases the situation in the electricity distribution, and therefore, such a methodology may provide companies with incentives to achieve short-term efficiency gains by neglecting even the necessary investments.

As it was stated above, the key reason why capital costs should be included in the benchmarking process is that the trade-off effects between the operational and capital costs could be removed, or at least alleviated, by that way. In other words, companies cannot increase their efficiency score by booking operational costs as capital costs or by favouring replacement investments instead of maintenance actions, if both of these cost items are included in the benchmarking. However, if capital costs are measured as straight-line depreciations, calculated based on the repurchase value of the network, then replacement investments do not affect these depreciations. That is because a pure replacement investment, where a network component is replaced by an identical component, does not increase the repurchase value of the network. In such a situation, a company can increase its efficiency score by booking a maintenance action as a replacement investment, for instance. Hence, there are still trade-off effects in such a model, but these effects are slighter than if the capital costs are not included at all. Furthermore, as it has been illustrated by the example, using the depreciations in the benchmarking is a better option than annual investment costs, when considering the directing signals of the regulation.

One relevant methodological question is whether capital costs are included in the benchmarking as a separate parameter, or if they are combined to other input parameters as total costs. As it is stated above, separate input parameters may blur the directing signals and provide companies with incentives to adopt an inefficient mix of input parameters. This is illustrated in Fig. 5.10., which presents the numbers of companies for which certain benchmarking parameters are insignificant. In this case, it is assumed that a benchmarking parameter is insignificant, if a one per cent decrease or increase in the parameter does not affect the efficiency score. Super efficiency model, described in section 2.2.1, is used, so that also the changes in the efficiency scores of the efficient companies are found. Efficiencies are calculated by the CRS DEA method with the data of the Finnish distribution companies. In both cases, the output parameters are the value of delivered energy, the network length, and the number of customers. The input parameters are operational expenses (OPEX), straight-line depreciations (SLD), and interruption costs (IC). In the first case, these are separate parameters, and hence there are three controlled input parameters in the benchmarking. In the second case, all these parameters are summed up, so that there is only one controlled input parameter in the benchmarking.

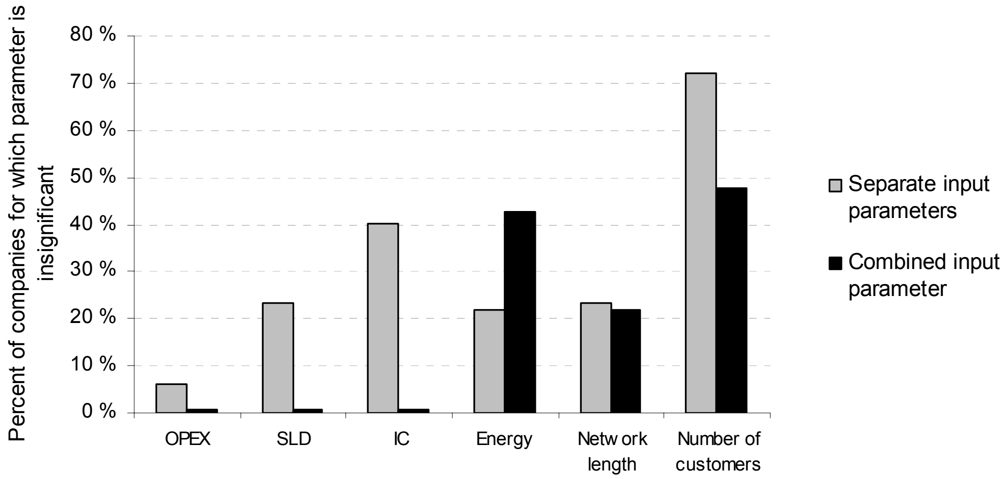

Figure 5.10. Share of companies for which the benchmarking parameter is insignificant. In this case, a parameter is interpreted as insignificant, if the change of 1 per cent in the parameter does not affect the efficiency score.

It can be seen from Fig. 5.10 that if the operational costs, depreciations, and capital costs are treated as separate parameters, they are insignificant for 6–40 % of companies, depending on the parameter. However, when the input parameters are combined as one parameter, they all are significant for every company. This is illustrated in the previous figure so that the values of the bars representing the insignificancy of the input parameters are zero in the case of the combined input parameters model. This is a clear evidence that the directing signals of the regulatory benchmarking can be improved by combining the input parameters.

5.5. Returns to scales

As it is discussed above, it is possible to make different assumptions about the returns to scale in the benchmarking process. Common approaches are constant returns to scale (CRS) and variable returns to scale (VRS), but also non-decreasing returns to scale (NDRS) or non-increasing returns to scale (NIRS) can be used. The main differences of these are that in the CRS model, it is assumed that all the companies are able to reach the same level of productivity, while in the other models, it is assumed that small companies (NDRS model), large companies (NIRS model) or both (VRS model) suffer from the non-optimal scale.

In the Finnish regulatory benchmarking, the VRS model has been used to compensate the possible scale inefficiency of small and large companies. When considering only from the company's point of view, it is natural that there is a certain amount of fixed costs, and hence small companies may not be able to reach the same level of productivity than large companies. Hence, the use of the variable or non-decreasing returns to scale assumption can be justified by the reason that companies cannot choose their scale of operation. However, when efficiency measurement is used as a regulatory tool, also the directing signals for the companies, as well as the viewpoint of the customers and society, should be taken into account. The major question is, whether the non-optimal scale of operation should be considered as the rationale for the higher costs, which most probably mean also higher prices paid by the customers of the monopoly company. Since the aim of the economic regulation should be to provide distribution companies with incentives to minimise their total costs, these companies should be encouraged to seek for an optimal scale of operation. However, since such an approach provides companies with incentives for mergers, political discussion is usually needed to decide whether decreasing the number of companies is included in the objectives of the economic regulation.

The mergers of at least the smallest companies lead most probably to lower total costs incurred by the customers in the long term. For instance, Filippini (1998) suggests, based on the empirical studies, that the consolidation of the small utilities in the Swiss electricity sector is likely to reduce costs. Yatchew (2000) has found evidence that the minimum efficient scale is achieved by companies with about 20 000 customers. In addition, Growitsch et al. (2005) have found in the efficiency evaluation of about 500 European distribution companies that even the largest company in the sample set has not exploited all the scale economies. However, in addition to the expected positive effects of the mergers, in some cases, there could also be negative impacts; for instance Jamasb et al. (2003) point out that mergers reduce the information of the regulator, which is a non-desirable effect especially in countries where the number of companies is small already.

In addition to the effects discussed above, measuring the efficiency of the smallest and largest companies may become problematic in the VRS model, because of the lack of peers for such companies, as have been reported for instance by Pedraja-Chaparro et al. (1999). To explicate further the nature of this problem, the efficiency measurement of nine units in the one input one output case is illustrated in both the CRS and VRS cases. Inputs and outputs of nine companies and the efficient frontier in the constant returns to scale model are plotted in Fig. 5.11. Here, it is assumed that the efficiency measurement is based on the input-oriented DEA model.

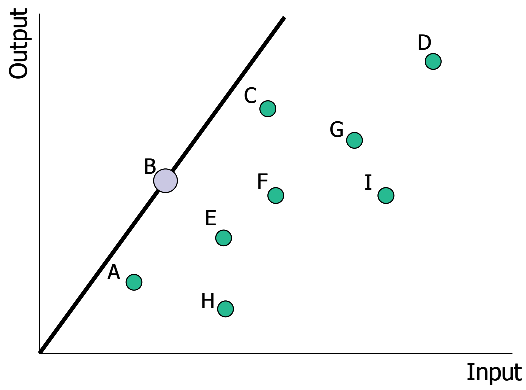

Figure 5.11. Example of the efficient frontier in the constant returns to scale model.

As we can see from the figure above, the efficiencies of all the companies can be determined based on the distance to the frontier. The only efficient unit is the company B, which defines the efficient frontier. However, if the company B increases its input usage with a constant amount of output production, it will move right in Fig. 5.11, and it will fall from the efficient frontier. Therefore, it can be said that in this case, the efficiency score of every company depends on their input usage. Hence, companies are provided with genuine efficiency incentives.

Similarly as in the previous figure, the inputs and outputs of the same companies are plotted in Fig. 5.12. However, this time, the efficient frontier is based on the variable returns to scale assumption.

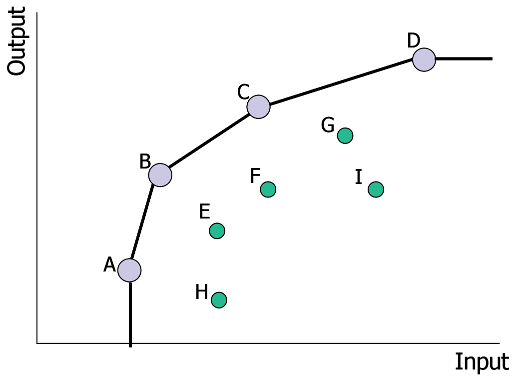

Figure 5.12. Example of the efficient frontier in the variable returns to scale model.

As we can see from Fig. 5.12, the companies A, B, C, and D are found efficient, and they form an efficient frontier in this case. However, if we consider the company D, it can increase its input usage unlimitedly, still remaining on the efficient frontier, if its output production remains the same and if all the other companies do not change their inputs or outputs. Similarly, a decrease in the output production of the company A does not affect its efficiency score. In other words, in this kind of a situation, efficiency benchmarking does not provide incentives for the reduction of the input usage for the company D.

The problem concerning the efficiency of large companies is analysed further by studying the efficiency score of a large Finnish distribution company from 1999 to 2004, shown in Fig. 5.13. In the same figure, also the operational costs of the company compared with the network length (€/m) are shown. The efficiency scores are calculated by the VRS and CRS DEA, and the input and output parameters are same as in the benchmarking model used previously in Finland, described in section 4.1.1.

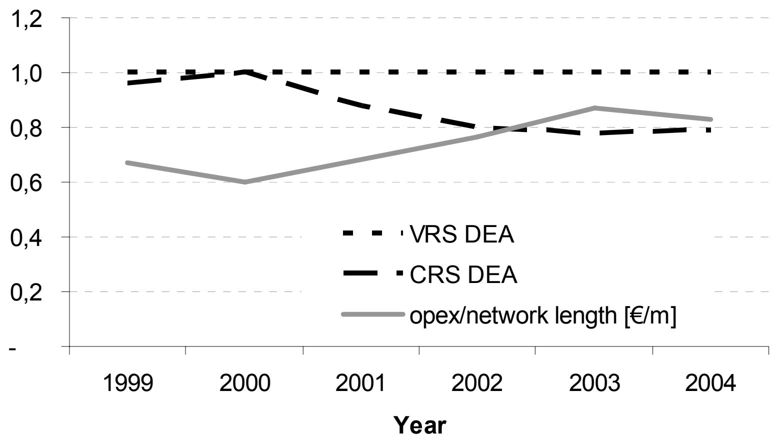

Figure 5.13. VRS and CRS DEA scores and the ratio of the operational costs to the network length for a large Finnish distribution company between 1999 and 2004 (Honkapuro et al. 2006c).

The figure above shows that the cost of the company per network length has decreased from 1999 to 2000, while from 2000 to 2003 it has been increasing, and in the year 2004, it decreased again. The CRS DEA scores have been following the changes in the costs logically, while the efficiency score has been decreasing as the costs have been increasing and vice versa. However, since this is one of the largest companies of the data set, the efficiency score of the VRS model tends to behave similarly as for the company D in the previous simplified example. Hence, the VRS DEA score remains at the value of 1.0, even though there is quite a significant increase in the costs. In practice, this may even lead to a situation, where the company benefits from increasing the inputs; this kind of a directing signal may appear if the increase in the inputs increases the cost base of the company, but does not decrease the efficiency score.

The differences in the VRS and CRS methods can also be illustrated by studying the distributions of the efficiency scores in both models. The distributions of the DEA scores in VRS and CRS models for the mid-sized Finnish distribution companies (the size of the company is measured by the length of the distribution network) are shown in Figs. 5.14. and 5.15.

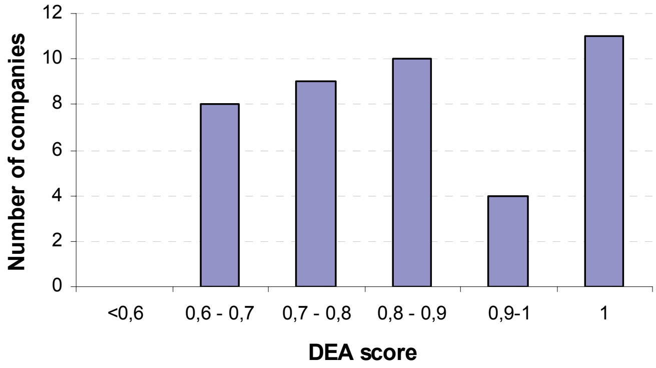

Figure 5.14. Distribution of the CRS DEA scores for 42 mid-sized Finnish distribution companies (Honkapuro et al. 2006c).

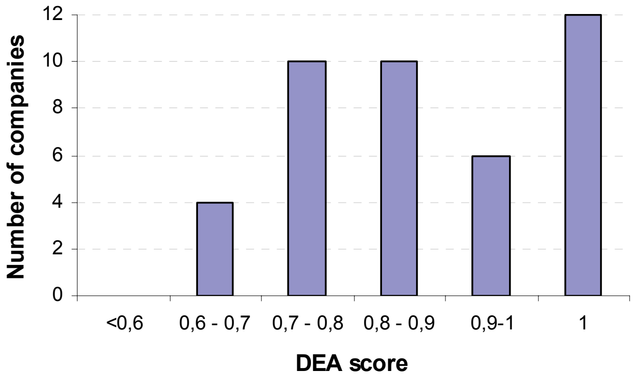

Figure 5.15. Distribution of the VRS DEA scores for 42 mid-sized Finnish distribution companies (Honkapuro et al. 2006c).

When comparing Figs. 5.14. and 5.15., we discover that the differences in the distribution of the efficiency scores of the CRS and VRS methods are quite small in the case of mid-sized companies. However, the situation is quite different, if we consider the largest companies, as we can see from Figs. 5.16. and 5.17., which show the distributions of the VRS and CRS DEA scores for the largest companies (measured by the length of the distribution network) that account for a quarter of all the Finnish distribution companies.

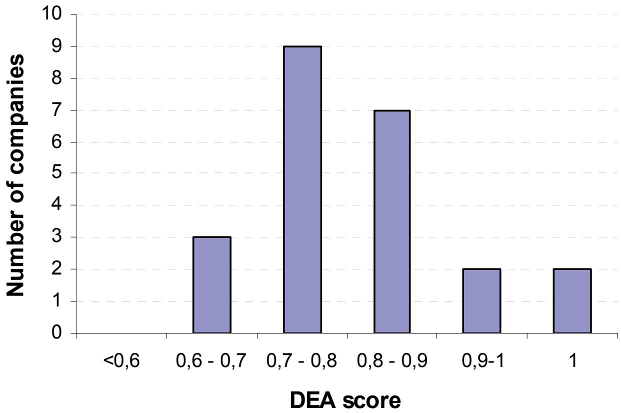

Figure 5.16. Distribution of the CRS DEA scores for the 23 largest companies that account for a quarter of all the Finnish distribution companies (Honkapuro et al. 2006c).

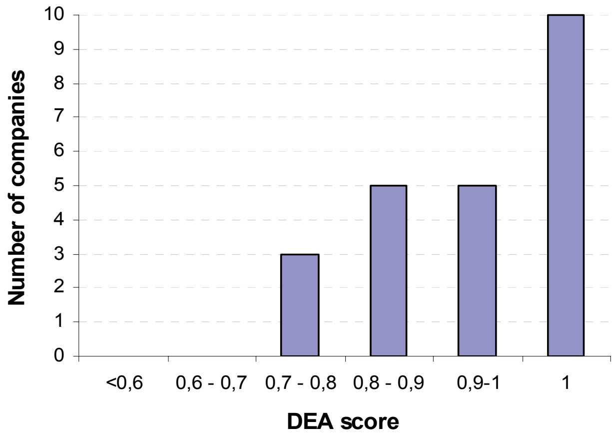

Figure 5.17. Distribution of the VRS DEA scores for the 23 largest companies that account for a quarter of all the Finnish distribution companies (Honkapuro et al. 2006c).

As it can be seen, the distribution of the CRS DEA efficiency score is somewhat similar to the standard distribution, while the distribution of the efficiency scores for the VRS method is clearly biased so that the efficiency scores are higher than in the case of CRS model. A similar illustration is presented in Figs. 5.18. and 5.19., which show the efficiency score distributions in the VRS and CRS methods for the smallest companies (measured by the length of the distribution network) that account for a quarter of all the Finnish distribution companies.

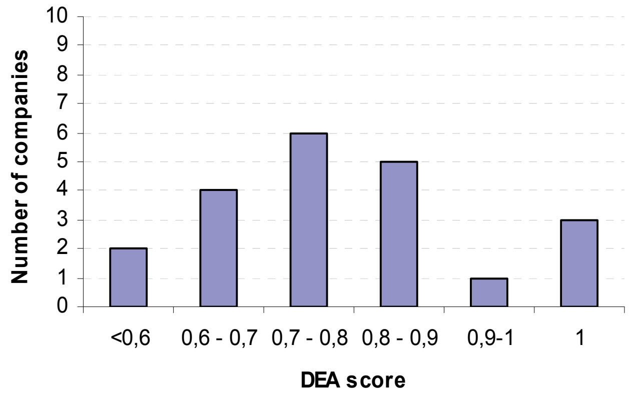

Figure 5.18. Distribution of the CRS DEA scores for the 21 smallest companies that account for a quarter of all the Finnish distribution companies (Honkapuro et al. 2006c).

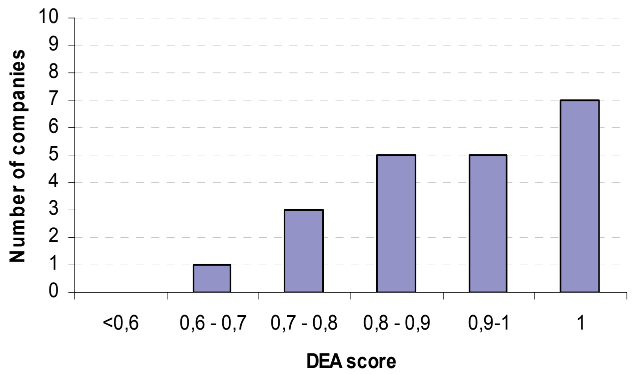

Figure 5.19. Distribution of the VRS DEA scores for the 21 smallest companies that account for a quarter of all the Finnish distribution companies (Honkapuro et al. 2006c).

Similarly, as in the case of the largest companies, also for the smallest companies, it seems that efficiency scores are biased in VRS model so that smallest companies are provided with higher efficiency scores than in CRS model.

Returns to scale also has effects on the profitability of the mergers. This effect is illustrated by the example study of the efficiency scores of a Finnish distribution company. In Table 5.3, the VRS, CRS, NDRS, and NIRS DEA methods are used to calculate the efficiency score for one small company, and one large company, which is formed by doubling all the input and output parameters of the small example company. By that way, the merger of two identical small companies is demonstrated. The input parameter of the model is the sum of the operational costs, interruption costs, and straight-line depreciations, while the output is the delivered energy and the environmental parameters are the network length and the number of customers.

Table 5.3. Efficiency scores of individual and merged companies.

Company	CRS DEA	VRS DEA	NDRS DEA	NIRS DEA
A	0.6315	0.9372	0.9372	0.6315
2 * A	0.6315	0.6764	0.6764	0.6315

As it can be seen from the table above, the efficiency score of the merged companies could be clearly lower than the efficiency score of an individual company in the VRS and NDRS models. However, this result is obviously company specific, and could be different for some other companies. Nevertheless, this example proves that incentives for mergers may be reduced because of the returns to scale assumption of the efficiency benchmarking. However, this result is considered solely from the viewpoint of the efficiency benchmarking. Naturally, companies may still benefit from the merger even if their efficiency scores decrease, if the economical gains of the merger are higher than the losses caused by the decrease in the efficiency score.

Based on the analysis presented in this section, it seems that the constant returns to scale model has some advantages compared with the variable returns to scale model, when considering from the directing signals' viewpoint. First, it directs companies to seek for the most efficient scale of operation through mergers, for instance. This means that the total costs of electricity distribution will be minimised. In addition, the method provides true efficiency incentives for all the companies, unlike the VRS model, where largest and smallest companies are always found efficient. Therefore, it was proposed by Honkapuro et al. (2006c) that VRS model should be replaced by the CRS model in the Finnish regulatory benchmarking to solve the problem concerning the efficiency measurement of the outlier companies. However, the EMA (2007a) decided to use the NDRS model to ensure that small companies are able to fulfil the efficiency requirement without having to change their scale of operation. In the case of large companies, the NDRS model is similar to the CRS model, but for the small companies, it behaves like the VRS model. Hence, the actual efficiency score of the largest companies can be determined, but the smallest company is always found efficient in the NDRS model. In addition, the incentives for mergers of the small companies may be reduced if NDRS model is used instead of CRS model, as illustrated above.

5.6. Applying benchmarking results in regulation

The regulation model was changed from the beginning of 2005 so that the decision about the reasonableness of pricing is made for a three years' regulatory period. In the earlier model, annual regulatory decisions were made, and the application methodology of the benchmarking was developed for such a model. Because of that, the application methodology had to be changed. However, there were also problematic issues in that methodology, when considering from the viewpoint of the directing signals.

In the regulatory model used in Finland before 2005, described in section 4.1.1., reasonable operational costs were determined based on the actual operational costs, efficiency score, and the error marginal, as presented in Equation (5.4).

$$RC_i = OPEX_i * \left(h_i + 0.1\right), \tag{5.4}$$

where

RC_i = reasonable controllable operational costs of the company i

$OPEX_i$ = actual controllable operational costs of the company i

h_i = efficiency score of the company i

If the company achieved efficiency score higher than 0.9, it was entitled to an efficiency bonus, the maximum amount of which was 10 % of the operational costs, as can be concluded from the equation above. However, this approach provides efficient companies with perverse directing signals to increase their cost base, since the efficiency bonus depends on the amount of the operational costs. Hence, if the efficiency score of the company remains at the efficient value, that is 1.0, even if the operational costs are increased, increasing of the costs would lead to increased allowed incomes. For example, if the operational costs of a company is 1 000 k€, and its efficiency score is 1.0, it is entitled to a 100 k€ efficiency bonus, which is additional profit for the company. However, if the company increases its costs to 1 100 k€, it is entitled to an efficiency bonus of 110 k€. Hence, the maximum profit of the company increases because of the increased operational costs. In addition, since the variable returns to scale DEA was used as a benchmarking method, there were actually companies that could increase their costs without any effects on the efficiency score, as shown in the previous section. Hence, the combination of the VRS DEA and this kind of an application of the benchmarking results provided quite distorted incentives for some companies.

5.7. Conclusions on the development of regulatory benchmarking

The development of the regulatory benchmarking, described in this chapter, has been based on the methodology, the basic idea of which is to analyse the effects of the benchmarking parameters to the efficiency score and to compare these results with the information about the role of the benchmarking in the regulatory framework. This way, the marginal price of the benchmarking parameter can be found. In addition to this, a same parameter can have other effects in the regulation, for instance investments can affect the regulatory asset base in the ROR regulation. In this analysis methodology, all these effects are simultaneously taken into account. Hence, the total economic effects of the parameters in the regulatory framework can be found. The methodology is implemented in practice by developing a software tool, which simulates the regulatory effects of the changes in the input data.

In the benchmarking model that was used before year 2005, which was the starting point of the development process, operational costs were the only controlled input parameter, and interruption time was a non-controlled input. In practice, this meant that the effect of the interruption time on the efficiency scores of the companies varied significantly between the companies and between the years. In addition, interruption time does not provide complete information about the power quality level of the company. Furthermore, capital costs were not included in the efficiency benchmarking, and hence, companies achieved efficiency gains by trade-offs between the operational and capital costs. In addition, the efficiency benchmarking methodology was DEA with a variable returns to scale (VRS) assumption, and therefore, the efficiency of the outlier companies was difficult to estimate.

If there are multiple input parameters in the benchmarking, the individual shadow price for each parameter is determined, and this price may vary between the companies and between the observation years. In that kind of a situation, the efficiency gains of the input reductions could be difficult to predict. Consequently, the directing signals of the efficiency benchmarking may become blurred, if the company cannot estimate the consequences of the changes in the input parameters. Furthermore, separate benchmarking parameters may lead to a situation, where an inefficient company may appear to be efficient because of only one deviating input factor. For example, if operational and capital costs are two separate input parameters, a company may appear to be efficient if its operational costs are at a very low level, even if its total costs were not at an efficient level. Similarly, if cost and quality are separate input parameters, company can be found efficient if its quality level is the highest of all companies, regardless of the level of its costs. Hence, combining all the inputs as a single parameter provides improvement in the directing signals of the benchmarking. This approach obviously requires the price information for each input parameters. This is obviously not a problem if all input parameters are annual cost items, which can be summed up to total costs. However, converting power quality or capital costs to annual cost items is not a simple process, as has been discussed in this thesis.

In the case of power quality, a further problem was the insufficient information that the interruption time provided about the quality levels of the companies. Hence, the most suitable development solution was to measure power quality as interruption costs, where both the number and duration of interruptions are taken into account and interruptions can be categorised to short and long interruptions and announced and unannounced ones. Furthermore, annual interruption costs could be summed to annual operational costs as single input parameter. Hence, the interruption costs incurred by the customers are internalised in the economy of the company. If also annual capital costs are summed in this total costs parameters, efficiency benchmarking directs companies to minimise the total costs, including interruption, operational, and capital costs.

When considering the capital costs in the benchmarking, the most suitable option turned out to be to use straight-line depreciations, calculated from the repurchase value of the distribution network, as an indicator of the annual capital costs. However, this approach did not solve all the problems, because some part of the trade-off effects between the operational and capital costs remained, since the replacement investments do not have an influence on the straight-line depreciations. Nevertheless, the directing signals are improved, when comparing with the previous model, because now the capital and operational costs have a similar effect on the efficiency score at least in the case of the extension investment. The drawback of such an approach is that the efficiency improvements of the straight-line depreciations are somewhat problematic, since decreasing such a cost item usually takes a long time. However, improving the efficiency of the capital costs is generally a long-term process, which has to be taken into account when deriving the efficiency requirements from the benchmarking results.

In the analysis concerning returns to scale assumptions, it has been shown that an increasing or variable returns to scale assumption might provide negative incentives for mergers, since in the worst case, the efficiency score of the merged company could be significantly lower than the original efficiency scores of the separate companies. However, this directing signal is considered solely from the viewpoint of the efficiency benchmarking. If the total benefits of the merger are higher than economical losses because of the reduced efficiency score, the merger is obviously economically beneficial. In the variable returns to scale model, the efficiency score of the largest and smallest companies is difficult to estimate, because in that model, such companies are always found efficient. Consequently, those companies are not necessary provided with genuine efficiency incentives. Hence, the efficiency incentives of the outlier companies can be improved by using the constant returns to scale (CRS) model instead of the VRS.

The actual economic effects of the efficiency benchmarking depend on the role of the benchmarking in the regulatory framework, and hence the issue had obviously to be considered during the development process. The evaluation of the implementation practice revealed for instance a directing signal in the regulatory benchmarking used before year 2005, in which some companies were actually incentivised to increase their operational costs. This was mainly because the additional efficiency bonus given for the most efficient companies depended on their cost levels. This is a practical lesson of the importance of the analyses of the directing signals during the development process of a regulatory framework.

Based on the development process, discussed in this chapter, proposals for the development of the benchmarking model were presented. These proposals, with some minor modifications, were included in the regulation model, applied in the second regulatory period, which will be presented in the next chapter.

6. Finnish regulatory model 2008–2011

This chapter introduces the new regulatory model, which is used in Finland during the second regulatory period that covers the years 2008–2011. The regulatory model and an analysis of its directing signals are presented. The chapter focuses on the practical implementation of the development results, presented in the previous chapter, and their effects on the directing signals of the regulation. Hence, the chapter provides information for the third objective of the thesis, the application of the analysis methodology of the efficiency benchmarking in practice. In addition, some comparisons between the Finnish model and regulation models used in the UK and Norway are made at the end of this chapter.

As it has been shown, there were certain development needs, mostly related to power quality and efficiency benchmarking, in the regulatory model applied during the first regulatory period 2005–2007. Therefore, the regulatory model has been developed further for the years 2008–2011, as described in the previous chapter and by the EMA (2007a). A simplified illustration of the regulation model is presented in Fig. 6.1.

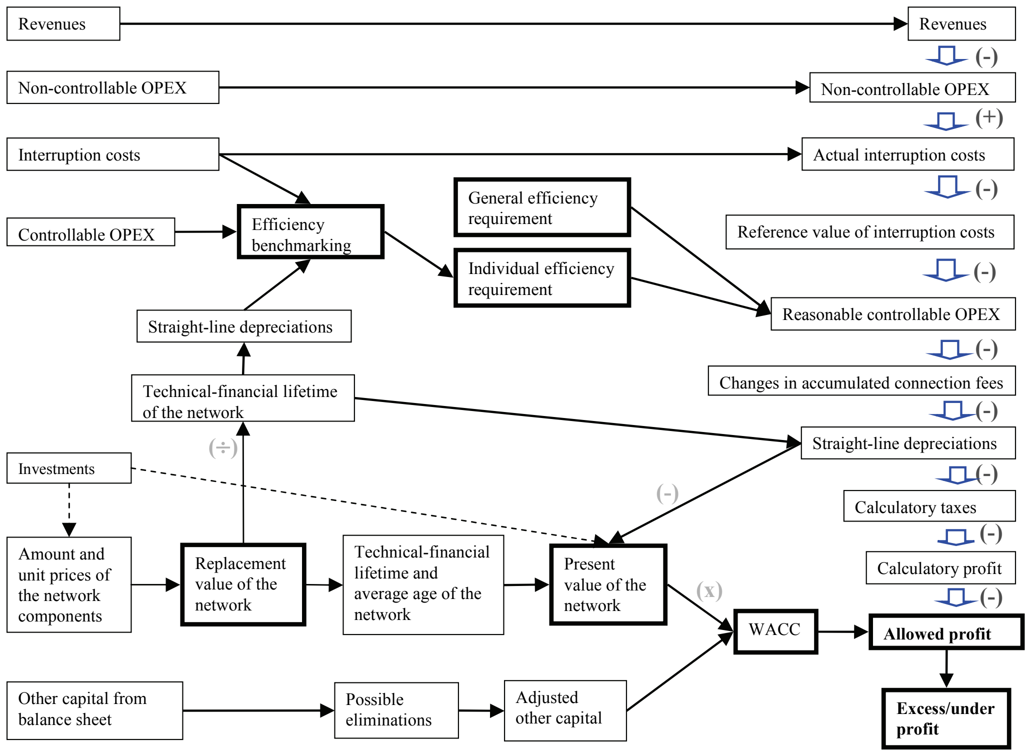

Figure 6.1. Simplified illustration of the regulation model in Finland between 2008 and 2011.

As shown in the figure above, the allowed profit in the regulation is defined based on the present value of the distribution network, and the straight-line depreciations of the distribution network are used to define the reasonable level of depreciations, similarly as in the previous model. Furthermore, present value of the network is updated annually based on the straight-line depreciations and network investments, same way as earlier. The most important changes concern the regulation of the quality of supply and the role of efficiency benchmarking. There is a minor change in the length of the regulatory period, which is four years, instead of the previous three-year period.

6.1. Efficiency benchmarking

One of the primary aims in the development of the regulation model for the second regulatory period has been adopting individual efficiency requirements in the regulation model. However, the previously used DEA model had to be developed further, before it could be used in determining the individual efficiency requirements, as has been discussed in the previous chapter. In the new DEA model, the input parameter is the sum of operational costs, straight-line depreciations, and interruption costs. Other parameters are the same as previously; the value of the delivered energy, the total length of the network, and the number of customers. The methodological change in the DEA is that the variable returns to scale model used previously is replaced by the non-decreasing returns to scale (NDRS) model to alleviate the problem concerning the outlier companies. The use of the NDRS model ensures that small companies do not suffer from the non-optimal scale of operation, but on the other hand, large companies are not favoured in the same way as in the variable returns to scale model. The object function of the new DEA model can be presented as shown in Equation (6.1) (EMA 2007a).

$$h_i = \frac{u_1 * energy_i + u_2 * network_i + u_3 * customers_i - u_0}{v_1 \left(OPEX_i + SLD_i + IC_i \right)}, \tag{6.1}$$

where

h_i	= DEA score of the company i
$energy_i$	= value of the delivered energy of the company i
$network_i$	= total length of the distribution network of the company i
$customers_i$	= number of customers of the company i
IC_i	= interruption costs of the company i
$OPEX_i$	= controllable operational costs of the company i
SLD_i	= straight-line depreciations of the company i
$u_{1\ldots3}$	= weight of the output parameter
v_1	= weight of the input parameter
u_0	= non-positive constraint, defining the non-decreasing returns to scale

In addition to the development of the DEA model, parallel efficiency benchmarking, based on the SFA method, was introduced (see Syrjänen et al. 2006). According to the EMA (2007a), input and output parameters of the SFA model are otherwise the same as in the DEA, but the network length is divided to the underground cables in the urban area and other network. These two models are used together, to increase the consistency of the benchmarking results. Efficiency score for each company is calculated as average of the DEA and SFA scores, as presented in Equation (6.2) (EMA 2007a).

$$ES_i = \frac{h_{DEA,i} + h_{SFA,i}}{2}, \tag{6.2}$$

where

ES_i = efficiency score of the company i

$h_{\mathrm{DEA,i}}$ = efficiency score of the company i, calculated by DEA

$h_{\mathrm{SFA,i}}$ = efficiency score of the company i, calculated by SFA

Efficiency scores calculated by the DEA and SFA methods for Finnish distribution companies are presented in Fig. 6.2.

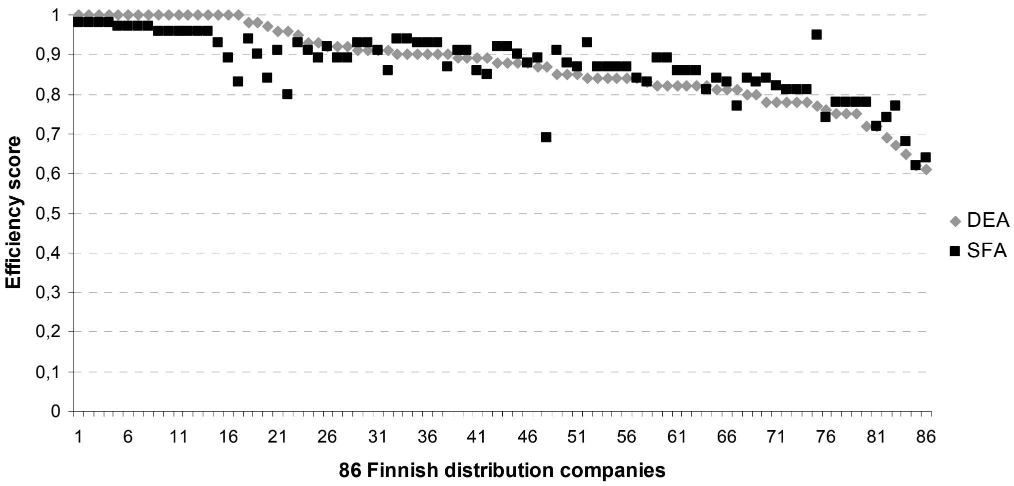

Figure 6.2. Efficiency scores calculated by the DEA and SFA methods for Finnish distribution companies.

However, although the reliability of the efficiency score is increased by using two parallel benchmarking models, there are still problems concerning the data quality; in practice, this is a consequence of the lack of long-term interruption data. As it was mentioned, new interruption indices, which are used for the calculation of the interruption costs, have been collected since 2005. Therefore, efficiency evaluation, which is needed before the beginning of the new regulatory period, has to be based on the interruption data of two years. Because there are significant annual variations in the interruptions, a two-year average of the interruption data may contain a significant amount of random error, and it does not necessarily reflect the typical quality level of the company. To minimise the risk that company gets too strict an efficiency requirement because of the random variation in the interruption data, the EMA (2007a) decided to add an error marginal in the efficiency requirement as shown in Equation (6.3). In addition, since the efficiency requirement focuses on the operational costs of the company, but the input parameter of the benchmarking is total costs, the efficiency requirement is adjusted by the ratio of these two parameters.

$$IER_i = (1 - ES_i) * 0{,}84 * \frac{OPEX_i}{TOTEX_i}, \tag{6.3}$$

where

IER_i	= individual efficiency requirement of the company i
$OPEX_i$	= operational costs of the company i
$TOTEX_i$	= total costs of the company i, including operational costs, interruption costs, and straight-line depreciations

According to the EMA (2007a), the time, in which companies are assumed to close the efficiency gap in the operational costs, is eight years. Therefore, the annual efficiency requirement is calculated as the eighth root of the total efficiency requirement, as shown in Equation (6.4).

$$IAER_i = 1 - \sqrt[8]{1 - IER_i} \,, \tag{6.4}$$

where

$IAER_i$ = individual annual efficiency requirement for the company i

Annual individual efficiency requirements for Finnish distribution companies are presented in Fig. 6.3.

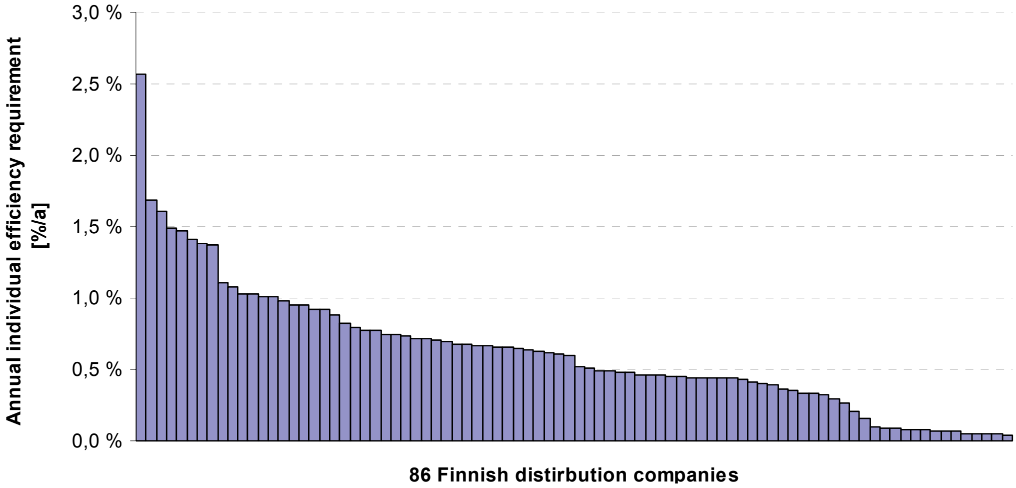

Figure 6.3. Annual individual efficiency requirements for Finnish distribution companies.

Total sum of these annual individual efficiency requirements is 2.5 M€, which is 0.23 per cent of the total revenue of these distribution companies.

In addition to the individual efficiency requirement, the general efficiency requirement, similar as in the first regulatory period, focuses on the operational costs of the company. However, while in the first regulatory period, the effect of inflation was taken into account by deducting the average inflation from the efficiency requirement, the effect of inflation is now taken into account by adjusting the reasonable costs by the annual changes in the value of the Building Cost Index (BCI) during the regulatory period. The general efficiency requirement is determined by a similar methodology as in the first period, based on the frontier shift of the DEA during the years 1999–2005. The annual general efficiency requirement is 2.06 per cent, which is slightly lower compared with 2.2 per cent in the first regulatory period. In addition, changes in the network volume have a similar effect as in the first period. Reasonable controllable operational costs can hence be calculated as presented in Equation (6.5) (EMA 2007a).

$$RC_{i,t} = (1 + \Delta BCI_t) * (1 + \Delta NV_{i,t}) * (1 - GER) * (1 - IAER_i) * RC_{i,t-1}, \quad (6.5)$$

where

$RC_{i,t}$ = reasonable controllable operational costs of the company i in year t

ΔBCI_t = change in the building cost index in year t

$\Delta NV_{i,t}$ = change in the network volume of the company i in year t

GER = annual general efficiency requirement

$IAER_i$ = annual individual efficiency requirement of the company i

6.2. Quality regulation

In addition to the efficiency benchmarking, the method for the regulation of the quality of supply had to be developed for the second regulatory period. In practice, there are several incentive mechanisms for the power quality. First, as it is presented in the previous section, interruption costs are a part of the input parameter of the efficiency benchmarking. Hence, changes in the interruption costs affect the efficiency score of the company. In addition, there is quality adjustment included in the economic regulation. In the quality adjustment, as it is clarified in section 3.5.3., the quality level of a distribution company is compared with the reference level of quality, and the allowed incomes are adjusted by the difference between the actual and reference quality level. In this case, the interruption costs of the distribution company are used as a quality index, and the reference value is determined based on the long-term interruption costs of the company. Similarly as in the efficiency benchmarking, the problem is the lack of the long-term data concerning the power quality, because the required quality indices are collected only from the year 2005 onwards. Hence, the reference value of the interruption costs cannot be defined prior to the regulatory period, but it will be determined as the average of the interruption costs from the years 2005–2008, as presented in (EMA 2007a). The annual interruption costs are compared with the reference value, and the allowed incomes of the company are adjusted by the half of the difference of the actual and reference value of the interruption costs. In addition, the effect of the quality adjustment is limited so that changes in the interruption costs can decrease or increase the allowed profit of the company by 10 per cent at maximum. The effect of the interruption costs is halved and limited to ensure that the economic consequences of the issues outside the companies' control, such as exceptional weather conditions, do not jeopardise the economy of the distribution company. According to the EMA (2007a), halving of the effect of the interruption costs ensure that also the customers gain benefit from the quality increases.

Since the compiled interruption indices are not divided according to the customer groups, the customer-specific outage cost parameters cannot be used. Hence, the outage cost parameters of different customer groups, presented in section 3.5.2., have been combined as one parameter per interruption type. These outage cost parameters, used by the Finnish regulator, are presented in Table 6.1. The parameters in Table 6.1 represent the price level of the year 2005, and they will be adjusted to the upcoming price levels by the changes in the building cost index (EMA 2007a).

Table 6.1. Outage cost parameters used by the Finnish regulator (EMA 2007a).

Unannounced outage		Announced outage		High-speed auto-reclose	Delayed auto-reclose
€/kW	€/kWh	€/kW	€/kWh	€/kW	€/kW
1.1	11.0	0.5	6.8	0.55	1.1

In addition to quality adjustment and efficiency benchmarking, the standard compensation scheme for the interruptions over 12 hours, illustrated in section 4.1.2, is still a part of the regulatory framework. Unlike earlier, standard compensation costs are not pass-through cost items, but they are included in the controlled operational costs in the new regulatory model. Therefore, these compensation costs decrease the profits of the companies directly and they affect the efficiency scores of the companies. In addition to the economic regulation, the interruption statistics of the distribution companies will most probably be published as before, which can be seen as indirect regulation that provides incentives through spill-over effects, as discussed previously.

6.3. Directing signals of the new regulatory model

Major changes in the regulation model of the second period, compared with the one used in the first period, are related to the role of the power quality and efficiency benchmarking, while the basic principles of the regulation, such as determining the allowed profit, remain the same. Minor modifications are found in the length of the regulatory period. A longer regulatory period, four years instead of the previous three years, increases the stability of the business environment in the short term. However, in electricity distribution, the technical-economic lifetimes of the investments are usually several decades. Hence, it is obvious that a distribution company should be able to estimate the effects of the investments for a longer time period than three or four years, and thus, a longer regulatory period improves the predictability of the model only slightly.

One of the major changes in the regulatory model is the introduction of individual efficiency requirements, based on the results of the efficiency benchmarking. Efficiency benchmarking was developed so that there are not only operational costs, but also straight-line depreciations and interruption costs in the input parameter. Therefore, efficiency benchmarking provides companies with incentives to optimise their total costs, and not only operational costs, as before. However, the efficiency requirement, determined based on the benchmarking results, focuses on the operational costs only. Thus, the directing signals of the regulation are somewhat unclear, since the efficiency of the total costs is benchmarked, but the decreasing requirement focuses on the operational costs only. Another modification in the efficiency benchmarking is in the return to scale assumption. The previously used variable returns to scale (VRS) DEA is replaced by the non-decreasing returns to scale (NDRS) DEA. In the NDRS DEA, it is assumed that small companies suffer from the suboptimal scale of the operation, while large companies can achieve the same level of productivity as mid-sized companies. Hence, the difference to the VRS model is that large companies are not favoured in the efficiency analysis. However, the directing signals for the mergers of the small companies are similar in both the VRS and NDRS models. The output and environmental parameters of the benchmarking remain the same: the value of the delivered energy, the network length, and the number of customers.

When considering the directing signals of the regulatory framework, the effects of the ROR regulation, the role of power quality, and the impacts of efficiency benchmarking are the major issues, which all have effects on the profitability of the investments. In addition, changes in the network volume affect the efficiency requirement. All these effects are illustrated in Fig. 6.4.

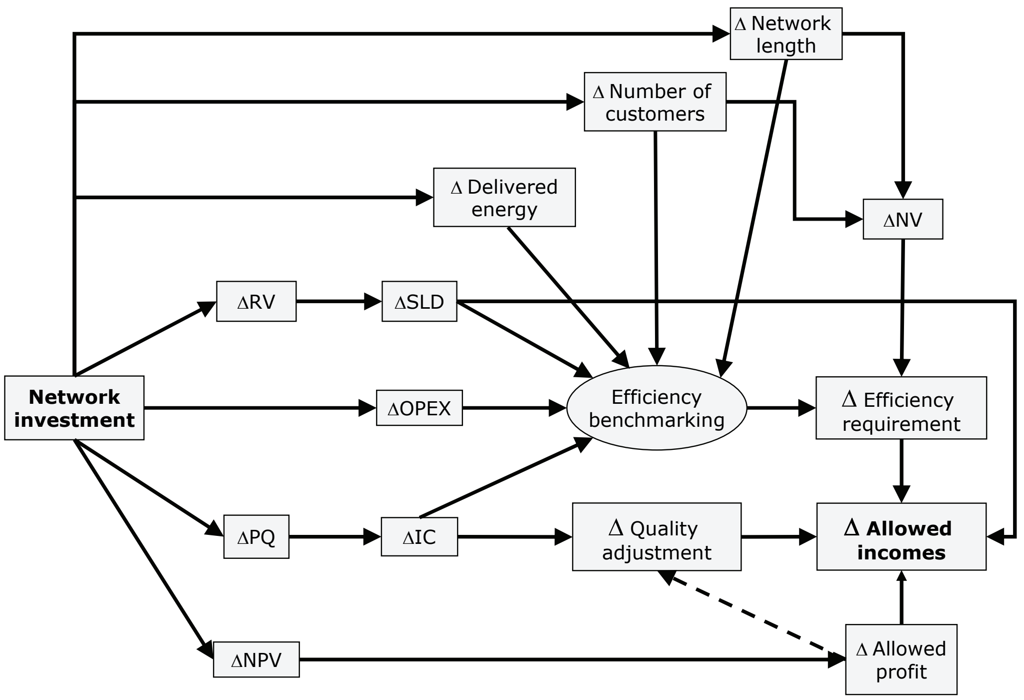

Figure 6.4. Effects of a network investment on the allowed incomes. NV = Network Volume, RV = Repurchase Value, SLD = Straight-Line Depreciations, PQ = Power Quality, IC = Interruption Costs, NPV = Net Present Value. The dashed line between the allowed profit and quality adjustment indicates the relation between these two items, since the cap in the quality adjustment is based on the allowed profit of the company.

The figure above illustrates the effects of a network investment on the allowed incomes in the new Finnish regulatory model. As we can see, the total effects are complicated, and the same issue may affect the allowed incomes in different ways, for instance power quality has an effect on the efficiency benchmarking and quality adjustment. In addition, these effects can be the opposite; for instance, straight-line depreciations increase the reasonable depreciation costs, used in the regulatory calculations, but simultaneously, they may decrease the efficiency score. Furthermore, different mechanisms have an effect for different time periods: Regulatory asset base is updated annually and therefore, an investment affects the allowed profit and depreciations immediately. In addition, annual interruption costs are compared with the reference value, and thereby a quality adjustment has an instant effect on the allowed incomes of the companies. On the other hand, efficiency benchmarking is based on the several years' data, and the efficiency requirement is determined for the whole regulatory period. Hence, efficiency benchmarking affects the allowed incomes from the beginning of the next regulatory period, while other incentive schemes have an instant effect on the allowed incomes. However, in the calculations presented in this thesis, it has been assumed that all these items affect at the same time. In addition, it is assumed that the reference values in the costs and quality remain stable. That way, it is possible to compare the effects of the different incentive schemes. In addition, if we assume that the reference value of the quality adjustment remains the same, the effects of the efficiency benchmarking and quality adjustment are similar during the next regulatory period after the investment.

The directing signals of this new regulatory framework are described in detail in the following sections. The effects of the efficiency benchmarking are analysed by using the DEA model only. However, similar analysis methodology can also be used to analyse the effects of the SFA model. In addition, since the effect of the changes in the output parameters varies greatly between the companies in the DEA model, only the changes in the input parameters are taken into account in the analysis. Furthermore, the adjustment parameter, in which the individual efficiency requirement is adjusted by the ratio of the operational costs to the total costs (see Eq. (6.3) in section 6.1), is not included in the analyses, since this addition to the model was made after the calculations and analyses were completed. In principle, the effect of this adjustment parameter is such that it decreases the efficiency requirement of the companies. The magnitude of the change in the efficiency requirement is high, if the amount of the operational costs compared with the total costs is low, and vice versa. In addition, such a parameter changes the economic effects of the input parameters, since changes in the cost components not only affect the input parameter of the benchmarking, but also the operational costs to total costs ratio.

6.3.1. Quality in regulation and efficiency benchmarking

The change in the economic effects of the quality of supply is quite dramatic in the new model; while quality did not have any economic effects during the first regulatory period, in the second period, there are three incentive mechanisms for the quality of supply. Although standard compensations for long interruptions have been introduced in 2003, they have previously been regarded as a pass-through cost item. In the new regulatory model, standard compensation costs are categorised as controllable operational costs, and hence they directly affect both the profit of the company and the input parameter of the efficiency benchmarking. Other incentive mechanisms for the quality of supply are quality adjustment and including interruption costs in the efficiency benchmarking. The effects of the interruptions on the allowed incomes and profits of a distribution company are illustrated in Fig. 6.5.

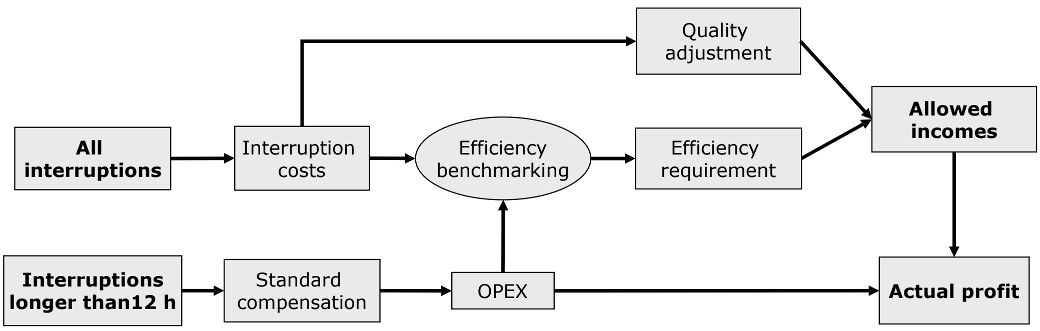

Figure 6.5. Effects of interruptions on the allowed incomes and profit of a distribution company.

However, while efficiency benchmarking and quality adjustment are two-way mechanisms, in other words, a company may get a penalty or an award from these mechanisms, the standard compensations scheme provides only penalties. In addition, although the quality adjustment is capped so that its maximum effect on the allowed profit is 10 per cent, the effects of the efficiency benchmarking and standard compensations are not limited. Hence, there is a risk that a major disturbance could dramatically shrink the profit and the upcoming allowed incomes of the company. It should also be noticed that these mechanisms affect at different times; standard compensations and quality adjustment have an instant effect on the profits of the company, while efficiency benchmarking affects the efficiency requirement during the next regulatory period. However, in these analyses, the effects of the efficiency benchmarking and quality adjustment are analysed assuming that they affect at the same time. This assumption is made to facilitate the comparison of the effects of these two incentive mechanisms.

Although there are incentives for increasing the quality of supply, the long-term economic effects of the quality improvements are still somewhat unclear. That is because it is unclear how the reference value of the interruption costs will be defined for the upcoming regulatory periods. The update of the reference value defines how a welfare increase, which is due to the quality improvement, or a decrease that is a consequence of the quality deterioration, is distributed between the company and the customers. Similarly, also the long-term distribution of the efficiency gains between the company and customers is unclear, since the method for the determination of the regulatory cost base for the third regulatory period is not known. During the second period, companies will be entitled to keep all the cost savings, but it is likely that at least some part of the efficiency gains is transferred to the customers after the period.

By a similar sensitivity analysis as presented in section 5.3., the marginal price for the power quality can be determined also in the new model. However, in the new regulatory model, the effect of the efficiency benchmarking will not be as direct as it was previously, since the annual efficiency requirement is calculated based on the eighth root of the efficiency score, as described above. Therefore, the economic effect of changes in the efficiency score, and hence the marginal price of the benchmarking parameters, will be generally lower compared with previous model.

First, we may analyse how the one per cent increase in the interruption costs affects the efficiency score of the companies. The result of this analysis is presented in Fig. 6.6.

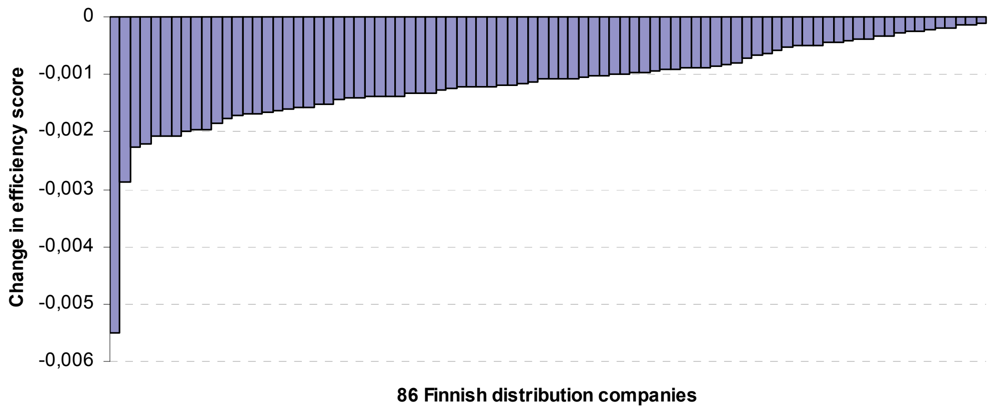

Figure 6.6. Effect of one per cent increase in the interruption cost on the DEA scores of the Finnish distribution companies, that is, the sensitivity of the efficiency score to the interruption costs.

We can see that an increase in the interruption cost has an effect on the efficiency scores of all the companies. This is one indication of the improvement of the directing signals in the new benchmarking model. However, the effects of the interruption costs on the efficiency score still vary between the companies. This is because the proportion of the interruption cost of the total costs varies between the companies, and hence a one per cent increase in the interruption costs has a varying percentage effect on the total costs.

In order to illustrate the economic effects of the interruption costs, the regulatory effect of the interruption cost of one euro is analysed next. Such a change in the interruption cost will change the efficiency scores and hence the efficiency requirements of the companies. In Fig. 6.7., the sensitivities of the efficiency scores to the interruption costs are presented for the Finnish distribution companies. In this case, sensitivity is measured as a change in the DEA score that is due to the increase of the one euro in the interruption costs.

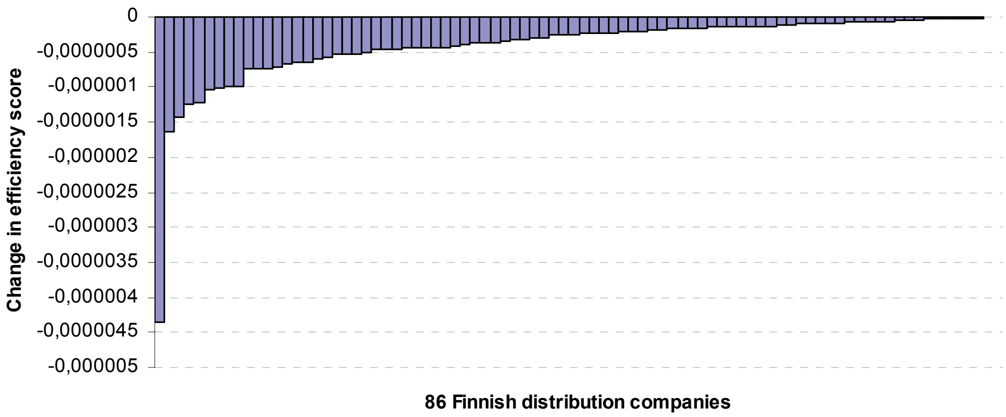

Figure 6.7. Effect of a one-euro increase in the interruption cost on the DEA scores of the Finnish distribution companies, that is the sensitivity of the efficiency score to the interruption costs.

The change in the efficiency score depends on the initial efficiency score and the relative change in the input parameter. Hence, the change in the efficiency score, which is due to a certain increase in the input parameter, is high if the total amount of the input parameter is low, and vice versa. The initial efficiency score, again, has an inverse effect so that the change in the efficiency score is high if the initial efficiency score is high, and vice versa. This is illustrated in Figs. 6.8. and 6.9., where the change in the efficiency score that is due to the one euro increase in the interruption costs is compared with the amount of the total costs and the initial efficiency score. In this case, also efficiency scores higher than 1 (also known as super efficiency) are calculated to find the changes in the efficiency scores of the efficient companies.

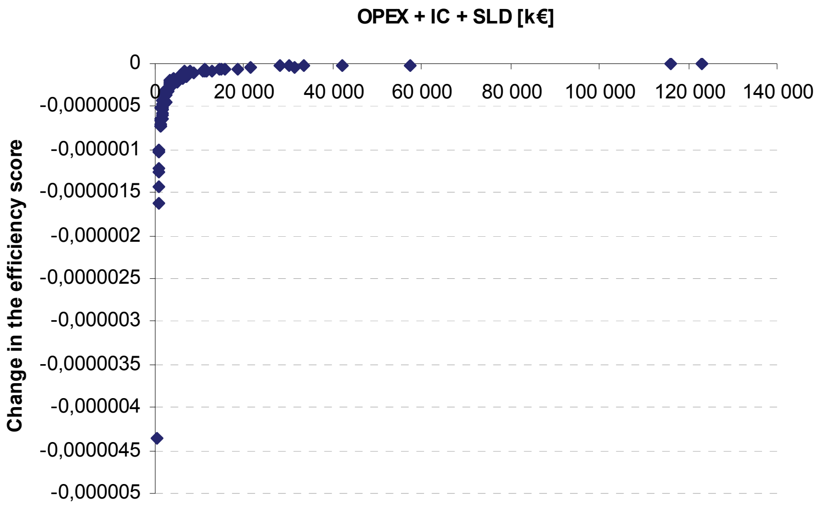

Figure 6.8. Changes in the DEA scores that are due to a one-euro increase in the interruption costs (the sensitivity of the efficiency score to the interruption costs), compared with the amount of the total costs.

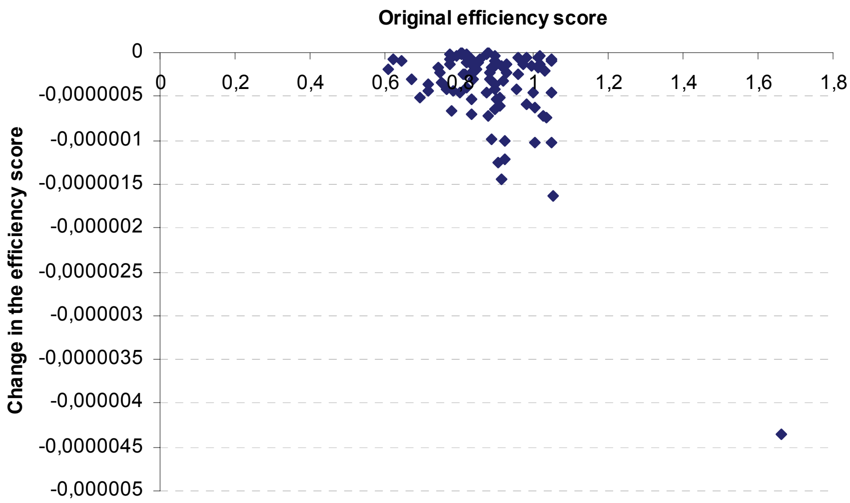

Figure 6.9. Changes in the DEA scores that are due to a one-euro increase in the interruption costs (the sensitivity of the efficiency score to the interruption costs), compared with the initial efficiency score.

However, when considering the economic effect of the efficiency benchmarking, the changes in the efficiency requirements, which are due to the changes in the efficiency scores, have to be determined. By that way, the marginal price of the benchmarking parameter, in this case the interruption costs, can be determined. These marginal prices, defined here as the change in the efficiency requirement that is due to the increase of one euro in the interruption costs, are presented in Fig. 6.10.

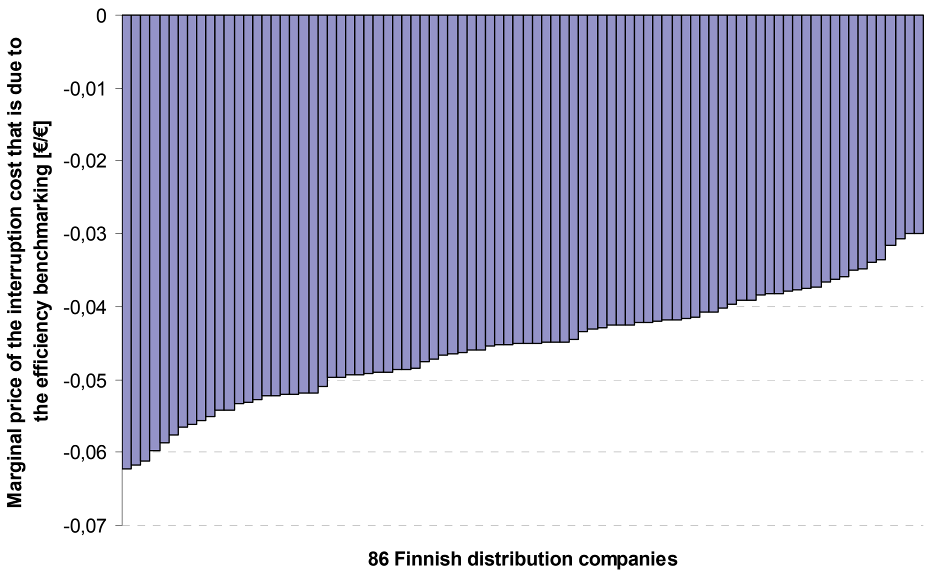

Figure 6.10. Marginal price of the interruption costs that is due to the efficiency benchmarking.

Since the efficiency requirement focuses on the operational costs, the economic effect of the efficiency benchmarking is dependent on the magnitude of the operational costs. On the other hand, the change in the efficiency score depends on the amount of the total costs. Hence, it can be concluded that the ratio of operational costs to the total costs affects the marginal price of the input parameter. This can be seen from Fig. 6.11., which presents the correlation between the marginal price and the proportion of the operational costs to the total costs.

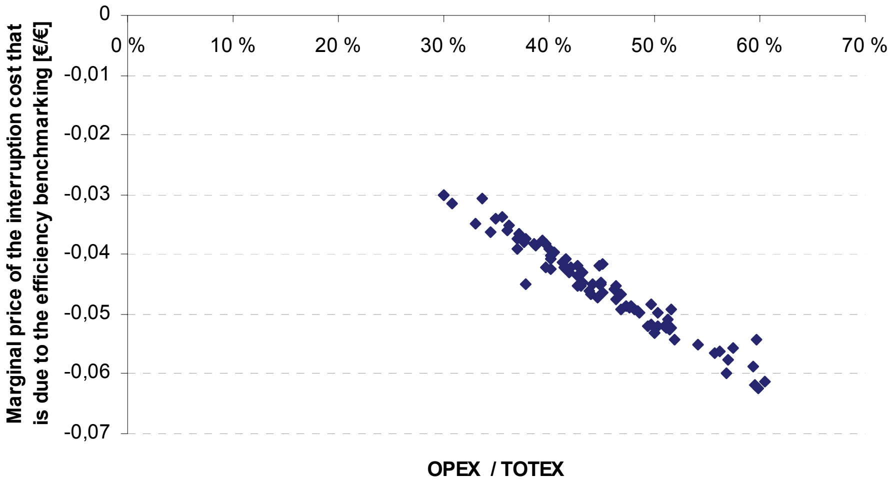

Figure 6.11. Correlation between the proportion of the operational costs (OPEX) to the total costs (TOTEX) and the marginal price of the interruption costs that is due to the efficiency benchmarking. In this case, the total cost is the sum of operational costs, interruption costs and straight-line depreciations.

As it can be seen, the variation in the economic effect of the input parameter, in this case the marginal price of the outage, is mostly due to the variation in the proportion of the operational costs to the total costs. That is because the efficiency requirement focuses on the operational costs, although the efficiency of the total costs is benchmarked. If the benchmarked parameter and focus of the efficiency score were the same, the total costs in this case, the variation in the marginal price would be slighter, as illustrated in Fig. 6.12.

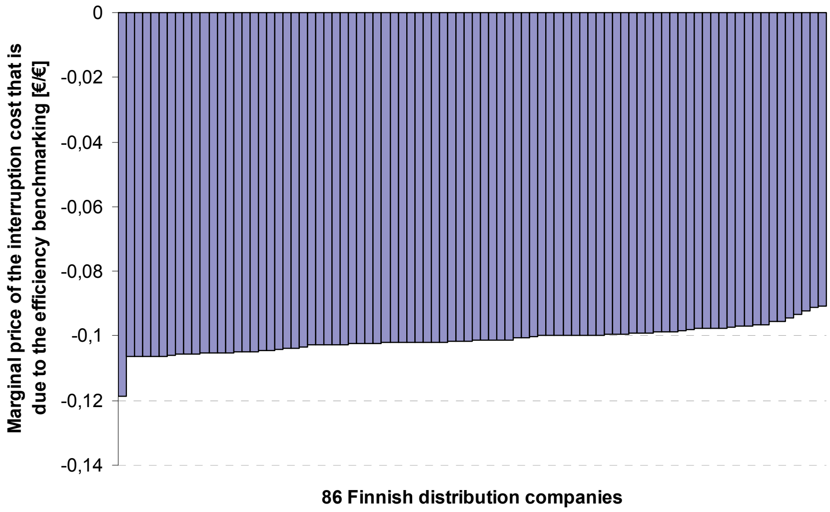

Figure 6.12. Marginal price of the interruption costs that is due to the efficiency benchmarking, if the efficiency requirement focuses on the total costs.

The variation in the efficiency requirement can be explained in this case by the differences in the initial efficiency score, as illustrated in Fig. 6.13.

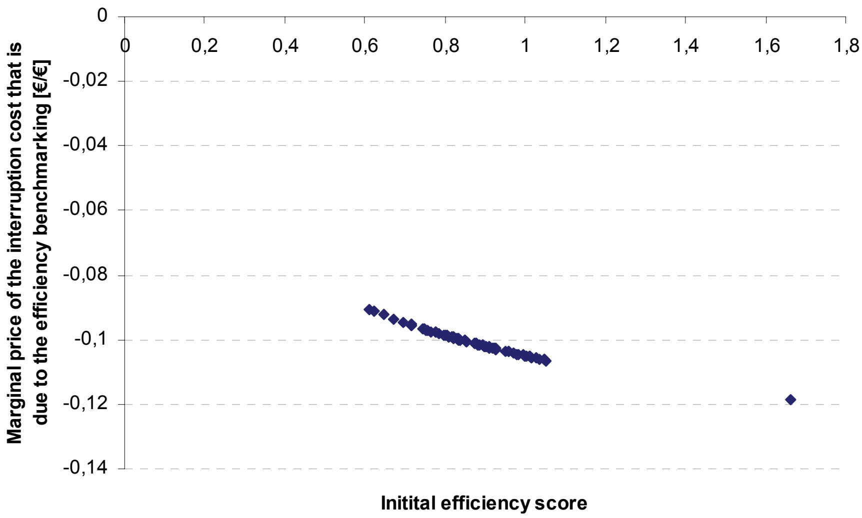

Figure 6.13. Correlation between the initial efficiency score and the marginal price of the interruption costs that is due to the efficiency benchmarking, if the efficiency requirement focuses on the total costs.

In addition to the effects of the efficiency benchmarking, a quality adjustment affects the allowed incomes of the companies in the Finnish regulatory model. The effect is half of the difference between the actual interruption costs and their reference value. The total marginal price of the interruption costs, in this case the change in the allowed incomes that is due to the one euro increase in the interruption costs, is presented for the Finnish distribution companies in Fig. 6.14. In that figure, the efficiency requirement is focused on operational costs, so that the effect of efficiency benchmarking varies between the companies as presented in Fig. 6.10.

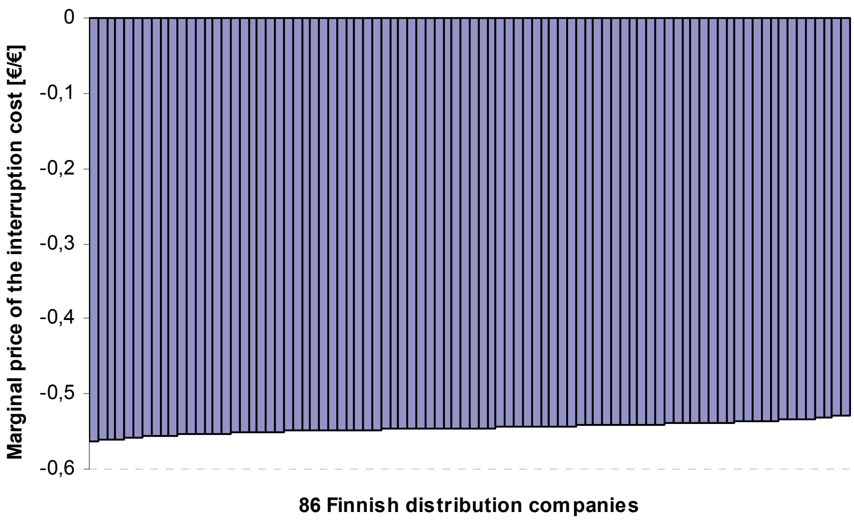

Figure 6.14. Marginal price of the interruption costs in the Finnish regulatory model.

Based on the analyses in this section, we may conclude that combining the interruption costs with other cost components as the only input parameter of the benchmarking improves the directing signals of the regulation. Fluctuation in the marginal prices of the interruptions between the companies is notably smaller than in the previous model, where the interruption time was a separate non-controlled input parameter. In addition, the reasons behind the fluctuations of the marginal prices can be defined, and hence the marginal price can actually be calculated by the companies, which increases the predictability of the model. However, the variations in the marginal price would be even lower if the efficiency requirement focused on total costs instead of operational costs. In addition, it can be seen from the calculations above that the effect of quality adjustment is significantly stronger than the effect of efficiency benchmarking, when considering the economic effects of power quality. Furthermore, as discussed earlier, quality adjustment affect the incomes of the company immediately, while the effect of the efficiency benchmarking will realise during the following regulatory period.

6.3.2. Capital costs in regulation and benchmarking

Capital costs have a two-sided role in the new regulatory model. The allowed profit is based on the present value of the network, and reasonable depreciation costs are determined based on the straight-line depreciations, calculated from the repurchase value of the network. Hence, the depreciation and financing costs of the investments can be collected from the customers as increased revenues. However, straight-line depreciations are also a part of the input parameter of the efficiency benchmarking. Therefore, increased depreciations decrease the efficiency score. Since these depreciations are based on the repurchase value of the network, extension and replacement investments have different regulatory effects.

Let us consider, as an example, the effects of an extension investment in the Finnish regulatory model. In this case, the investment cost is 40 k€, and the technical-economic lifetime of the investment is 40 years. Further, since this is a purely theoretical example, we may assume that the investment does not have any other effects than its capital costs, and it does not affect the network volume. In practice, such an investment could be for instance increasing the transformer capacity. Hence, we can concentrate on studying the effects of these capital costs on the allowed revenue of the company.

First, the effects of the efficiency benchmarking are studied. Since the sum of the operational cost, interruption costs, and straight-line depreciations form an input parameter of the benchmarking, an extension investment decreases the efficiency score, if its annual straight-line depreciations are higher than savings in the operational or interruption costs. In this case, the investment does not affect the interruption costs or operational costs at all, but it increases the annual straight-line depreciations by 1 k€, and hence the investment decreases the efficiency scores. The effect of this example investment on the efficiency scores of the Finnish distribution companies are presented in Fig. 6.15.

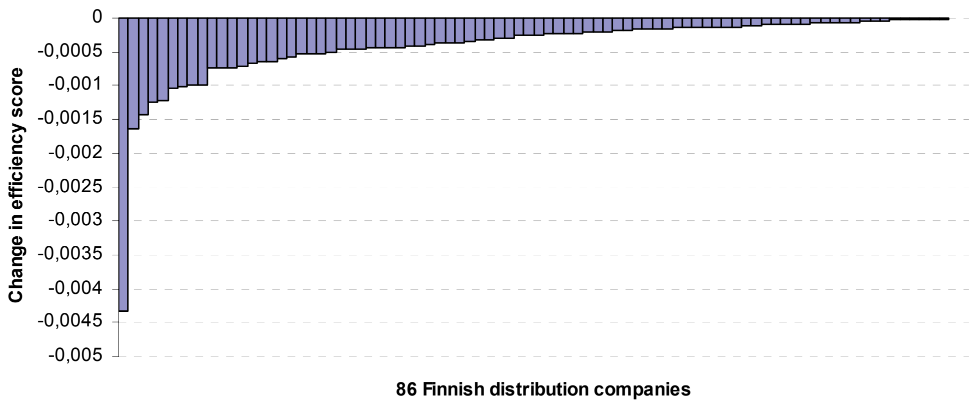

Figure 6.15. Influence of the example investment on the efficiency score.

Similarly as in the case of the interruption costs, the change in the efficiency score, caused by the example investment, varies between the companies, as it can be seen from the figure above. As it was shown in the previous section, this variation is due to the differences in the initial efficiency scores as well as the amount of the total input parameter. In addition, the economic effect of the efficiency benchmarking depends on the magnitude of the operational costs, as has been demonstrated in the previous section. Hence, the benchmarking effect of the example investment for the Finnish distribution companies varies as presented in Fig 6.16.

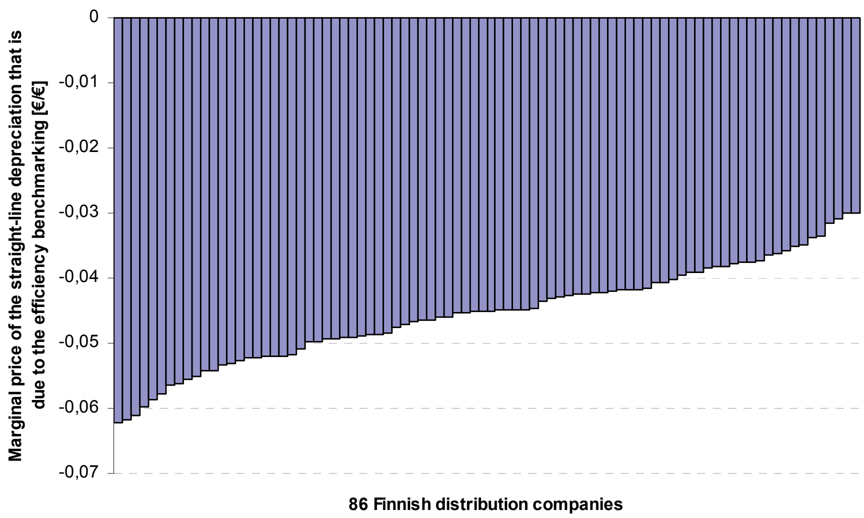

Figure 6.16. Marginal price of the straight-line depreciation, caused by the efficiency benchmarking.

However, despite the negative effects of the investment, caused by the efficiency benchmarking, the investment eventually increases the allowed incomes by increasing the allowed depreciations and profit.

An increase in the present value of the network, which leads to the increased allowed profit, will decrease annually by the value of the straight-line depreciations. The depreciation level, however, remains the same during the whole lifetime of the investment. If we assume that there are no other changes in the data set of the efficiency benchmarking, also the efficiency requirement remains the same. This is obviously a fully theoretical assumption, and in practice, there are naturally changes in the input data of the benchmarking during the years. The economic effects of the example 40 k€ extension investments during its lifetime, which is 40 years, are presented in Fig. 6.17. Since the effect of the efficiency benchmarking varies between the companies, as can be seen from Fig. 6.16., the average value of the benchmarking effect is used in the next figure.

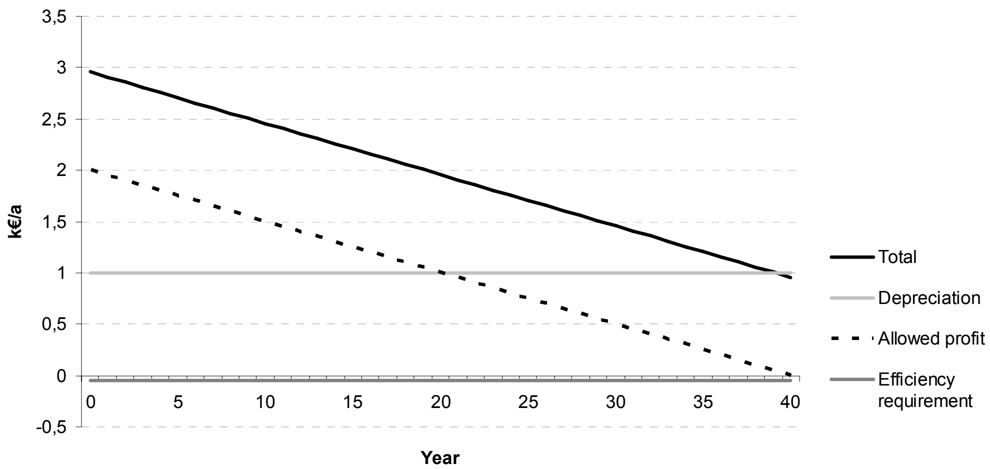

Figure 6.17. Effects of the example extension investment on the annual allowed revenue during the lifetime of the investment.

As it can be seen from the figure above, the economic effect of efficiency benchmarking is minor, when it is compared with the direct effects of the regulation. However, although the economic effect of the benchmarking is small, the directing signal is such that efficiency is improved, if the total costs including operational, depreciation, and interruption costs are minimised. It should also be noticed that in practice, efficiency benchmarking affects the allowed incomes from the beginning of the next regulatory period, while the effects in the regulatory asset base and reasonable depreciations are updated annually. However, in this example, to be able to compare the effects, we may assume that all these effects occur simultaneously.

However, the effects of the investment depend on the investment type; extension and replacement investment have different economic effects. If the previous example investment had been a replacement investment, instead of an extension investment, its effects on the allowed income would have been different. In such a case, straight-line depreciations remain the same, and hence there are no changes in the efficiency requirement; nevertheless, also reasonable depreciation costs are not increased by the investment. Therefore, the only effect of such an investment would have been an increase in the allowed profit. The economic effects of the 40 k€ replacement investment during its lifetime, which is 40 years, are illustrated in Fig. 6.18.

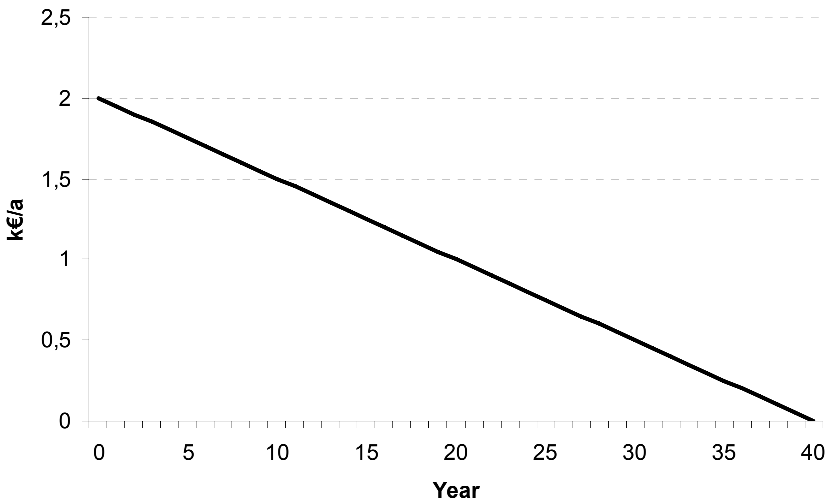

Figure 6.18. Effects of the example replacement investment on the annual allowed revenue during the lifetime of the investment.

When comparing Figs. 6.17. and 6.18., we may see that although the extension investment decreases the efficiency score, it increases the allowed incomes more than a replacement investment.

6.3.3. Applying benchmarking results in economic regulation

A usual approach to include benchmarking in the economic regulation is to derive an efficiency requirement, that is, an X-factor, from the benchmarking results. Such an efficiency requirement can be focused either on the total revenue of the company or on an individual cost item, usually operational costs. Basically, the effect of the efficiency benchmarking is similar in both cases; it decrease the allowed revenue of the company by the estimated efficiency improvement potential. However, in practice, there are obvious differences in these two approaches, which is illustrated in this section.

A theoretical representation of the regulation model, where the efficiency requirement focuses on the operational costs is presented in Fig. 6.19. In the illustration, the allowed revenue is determined as the sum of the allowed return on capital, allowed depreciations, and allowed operational costs. The effect of the efficiency benchmarking in that model is such that the allowed revenue is decreased by the product of the efficiency requirement and operational costs.

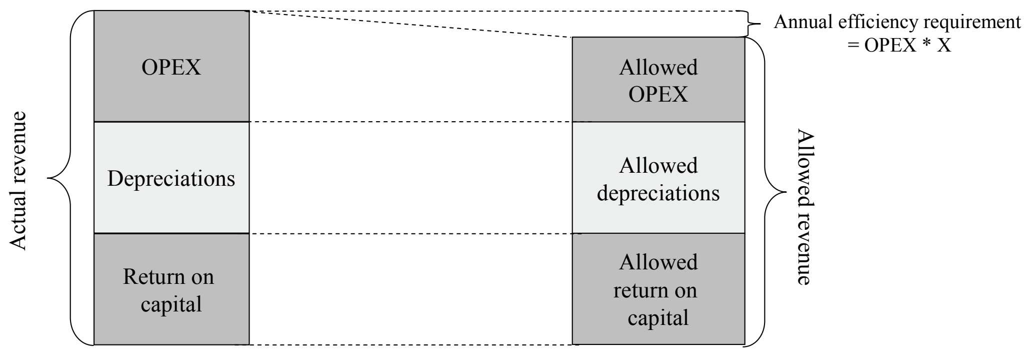

Figure 6.19. Efficiency requirement focusing on the OPEX.

Fig. 6.20. depicts how the efficiency requirement focuses on the total revenue of the company. In this case, the allowed revenue is decreased annually by the product of the allowed revenue and the efficiency requirement.

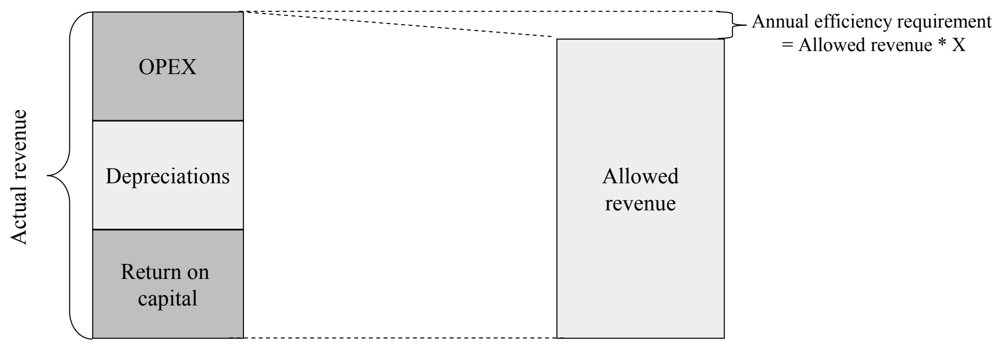

Figure 6.20. Efficiency requirement focusing on the total revenue.

As can be discovered from the figures, in the latter approach, there is no need to determine the reasonable levels for the individual cost components, such as depreciations or operational costs, but only the total revenue is limited. When the efficiency requirement focuses on the operational costs only, also the reasonable levels of other cost items, such as depreciations and return on capital, have to be determined. Although the allowed revenue is eventually determined in both approaches, the first one provides, at least theoretically, stricter limits for individual cost components, and thereby provides companies with more precise guidelines for their cost structures. However, even though the regulator sets the limits for individual cost components, the approach in the supervision might be to use these limits only to form the total amount of the allowed revenue, and thus the regulation may actually focus on the total revenue.

However, economic consequences of efficiency benchmarking may be significantly different, depending on the focus of the efficiency requirement. This can be demonstrated by a simplified theoretical example, where the efficiency requirements of two companies are compared. The basic information about these two example companies is presented in Table 6.2.

Table 6.2. Initial data about the example companies.

	Company A	Company B
Efficiency score	0.8	0.8
Operational costs [k€]	6 000	4 000
Repurchase value of the network [k€]	160 000	240 000
Depreciation time of the network [k€]	40	40
Straight-line depreciation [k€/a]	4 000	6 000
Average age of the network [a]	25	30
Present value of the network [k€]	60 000	60 000
Regulatory rate of return [%]	5 %	5 %
Allowed profit [k€/a]	3 000	3 000

Based on the information of the table above, it could be considered that the company A has more overhead lines than the company B, since its operational costs are higher and the repurchase value of the network is lower. However, since B has an older network than A, the present value of the network, and hence the allowed profits of the companies are equal. Furthermore, it can be seen that the sum of the profit, depreciations and operational costs, which can be considered as allowed revenue, is equal for both companies. In addition, the efficiency score is the same for both companies.

Let us next consider the efficiency requirements of these companies. We can derive the annual efficiency requirement from the efficiency score using the same equation, which is applied in Finland during the second regulatory period. However, derivation of the efficiency requirement from the efficiency score is actually not a relevant issue in this example, but more interesting is the focus of the efficiency requirement. In Table 6.3., the annual efficiency requirements for both example companies are calculated by using two approaches. In the first case, the efficiency requirement focuses on the operational cost, while in the second case, it focuses on the allowed revenue, which in this example is the sum of the operational costs, straight-line depreciations and allowed profit.

Table 6.3. Efficiency requirement for the example companies.

		Company A	Company B
Efficiency requirement [%/a]		2.27	2.27
Revenue reduction requirement [k€/a]	Efficiency requirement focus on OPEX	136	91
	Efficiency requirement focus on allowed revenue	295	295

As it can be seen from the table above, if the annual efficiency requirement focuses on the allowed revenue, it is equal for both companies. However, if the requirement focuses on the operational costs, it is different for these companies, since they have different operational costs. Although this is only a theoretical example, it shows that an efficiency requirement focusing on an individual cost component could be problematic, since its economic effects depend on the costs structure of the company.

6.3.4. Examples on the regulatory effects of network investments

As an illustration of the directing signals, the regulatory effects of the certain network investments in the new and previous Finnish regulation models are analysed for an example distribution company. The effects of the investments on the allowed return, as well as the efficiency requirement and quality adjustment are considered. However, in the analysis of the efficiency benchmarking, only the effects of input parameters are taken into account. In addition, the reference value of the quality and regulatory cost base are assumed to remain stable, and it is assumed that the effects of the investment on the actual costs and quality are instant. Furthermore, it is assumed that also efficiency benchmarking has an immediate effect on the allowed incomes of the company. Possible dismantling costs of the existing network are ignored. The initial information about the example distribution company is presented in Table 6.4. Actual depreciations of the company is thought to be equal to the straight-line depreciations, calculated from the repurchase value of the network. The allowed rate of return in these calculations is assumed to be 5 %.

Table 6.4. Initial data about the example company.

Length of 110 kV overhead lines	3 km
Length of 110 kV underground cables	0 km
Length of medium voltage overhead lines	1300 km
Length of medium voltage underground cables	50 km
Length of low voltage lines	2000 km
Number of customer	15 000
Network volume	2792.6
Annual straight-line depreciations	2000 k€/a
Average annual operational costs	2000 k€/a
Average annual interruption time	3 h/customer,a (45 000 customer,h/a in total)
Average annual interruption costs	1000 k€/a
Initial efficiency score	0.9

The regulatory effects of the four example network investments will be calculated in the following sections. These will be (1) an extension investment, where a new back-up line is built, (2) replacing the existing overhead line with an underground cable, (3) renewing a part of the existing network with identical components at the end of the lifetime, and (4) a similar replacement investment in the middle of the lifetime.

6.3.4.1. Example 1: New back-up line

In this example, we study how building of a new back-up line affects the allowed incomes of the company. The new back-up overhead line is built to the medium-voltage network so that the total length of the network will increase by 23 km. The cost of the investment will be 500 k€, by which amount also the repurchase and present value of the network will increase. The depreciation time of the investment is 40 years. Because of the investment, the annual interruption time will decrease by 1 800 customer,h, which means a 40 k€ in interruption cost, and the annual operational costs will increase by 3 k€.

First, the effects of this investment in the new regulation model are studied. Since the increase in the present value of the network is 500 k€, the increase in the allowed profit will be 25 k€ in the first year after the investment. This will decrease to zero during the lifetime of the investment. The repurchase value of the network will also increase by 500 k€, and because of that, there will be an increase of 12.5 k€ in the straight-line depreciations. In addition to the changes in the straight-line depreciations, the changes in the interruption and operational costs will affect the efficiency score of the company. The total decrease in the input parameter of the efficiency benchmarking will be 24.5 k€, which will cause an increase of 0.4 percentage unit in the efficiency score. Furthermore, this will result in a 0.05 percentage unit decrease in the annual individual efficiency requirement, and hence, a 1 k€ increase in the reasonable operational costs. In addition, the network volume will increase by 0.8 %, which will lead to a 16.5 k€ increase in the reasonable operational costs. Additionally, the allowed incomes will be adjusted by a half of the difference between the actual and reference level of the interruption costs. Hence, in this case, the quality adjustment increases the allowed incomes by a half of the decrease of the interruption costs, that is, 20 k€. The total regulatory effects of the example investment are presented in Table 6.5.

Table 6.5. Regulatory effects of the example investment in new regulatory model.

Change in the allowed profit (in the 1st year after the investment)	+ 25 k€
Change in the reasonable depreciations (= straight-line depreciations)	+ 12.5 k€
Change in the reasonable operational costs that is due to the change in the individual efficiency requirement	+ 1 k€
Change in the reasonable operational costs that is due to the change in the network volume	+ 16.5 k€
Change in the quality adjustment	+ 20 k€
Total effect on the allowed incomes (in the 1st year after the investment)	+ 75 k€
Return on investment in the first year = (increase in allowed incomes – increase in annual operational and depreciation expenses) / investment costs	11.9 %

The increase in the annual allowed income of the company that is due to the example investment is 75 k€ in the first year after the investment, while the increase in the annual operational costs is 3 k€ and increase in the annual depreciations is 12.5 k€. Hence, the return on investment in the first year (calculated by subtracting the increase in operational and depreciation expenses from the increase in the allowed incomes and dividing this figure by the investment cost) is 11.9 %, while the initial regulatory rate of return accounted in the example was 5 %. We can see that in addition to the increase in the regulatory-allowed profit, the increase in the network volume and the change in the quality adjustment turned out to be the most important factors for the return on investment in the new regulatory model, while the effect of the efficiency benchmarking was less significant.

In the regulatory model, which was applied in Finland during the years 2005–2007, the effects on the allowed profits, depreciations and network volume were similar as in the new model. However, efficiency benchmarking and quality adjustment were not included in that model. The increase in the allowed incomes owing to this example investment would have been in that model 54 k€ and return on investment 7.7 %, as illustrated in Table 6.6.

Table 6.6. Regulatory effects of the example investment in the regulatory model applied in 2005–2007.

Change in the allowed profit (in the 1st year after the investment)	+ 25 k€
Change in the reasonable depreciations (= straight-line depreciations)	+ 12.5 k€
Change in the reasonable operational costs that is due to the change in the network volume	+ 16.5 k€
Total effect on the allowed incomes (in the 1st year after the investment)	+ 54 k€
Return on investment in the first year = (increase in allowed incomes – increase in annual operational and depreciation expenses) / investment costs	7.7 %

The effect of this example investment on the allowed profit was similar also in the model, which was used before year 2005. However, in that model, reasonable depreciations were defined as the average of the three years investment costs. Hence, this investment would have increased the allowed depreciations in such a model by 167 k€. Therefore, the total increase in the allowed incomes would have been 192 k€, while increase in straight-line depreciations were 12.5 k€ and increase in operational expenses 3 k€. This would have meant that the return on investment in the first year would have been as high as 35.3 %. However, in this figure, the effect of the efficiency benchmarking is not yet taken into account. As it has been described earlier, efficiency benchmarking was used as part of the regulatory decision, if it was beneficial for the company, that is, if its efficiency score was higher than 0.9. In order to estimate the economic effects of the efficiency benchmarking, let us assume that benchmarking would have been used as a part of the regulatory calculations for this example company.

Since operational costs were the only controlled input parameter in that model, their effects on the efficiency score can be calculated as have been illustrated previously in this thesis. Hence, the efficiency score will decrease by 0.1 percentage unit owing to the increase of 3 k€ in operational costs. However, the effect of the interruption time on the efficiency score of the company was more difficult to predict, as it has been shown above. Because of this example investment, the interruption time of the example company will decrease by 4 per cent. As it has been shown in section 5.3., the effect of the interruption time on the efficiency score varied significantly between the companies. Hence, a 4 per cent decrease in the interruption time would have increased the efficiency score by 0–4.8 percentage unit, depending on the company and review year. Therefore, the total effect of this example investment on the efficiency score varies between -0.1 and +4.7 percentage unit. The reasonable operational costs were calculated in that model, based on the actual costs and the efficiency score, as discussed above. Because of this example investment, the actual operational costs increase by 3 k€, and the effect of the investment on the efficiency score varies, as illustrated above. Hence, if the efficiency score decreases by 0.1 percentage unit, the allowed operational costs after the investment will be:

$$2003 \text{ k€} * (0.899 + 0.1) = 2001 \text{ k€}$$

Again, if the efficiency score will increase by 4.7 percentage unit, the allowed operational costs will be:

$$2003 \text{ k€} * (0.947 + 0.1) = 2097 \text{ k€}$$

Hence, the increase in the allowed operational costs will vary between 1 and 97 k€. The total regulatory effects of the example investment are presented in Table 6.7.

Table 6.7. Regulatory effects of the example investment in the regulatory model applied before year 2005.

Change in the allowed profit (in the 1st year after the investment)	+ 25 k€
Change in the reasonable depreciations (in the 1st year after the investment)	+ 167 k€
Change in the reasonable operational costs that is due to the efficiency benchmarking	+1 … 97 k€
Total effect on the allowed incomes (in the 1st year after the investment)	+ 193 … 289 k€
Return on investment in the first year = (increase in allowed incomes – increase in annual operational and depreciation expenses) / investment costs	35.5 … 54.7 %

It can be seen that in the regulation model, applied before the year 2005, incentives for the investments were particularly strong, because of the method for determining the reasonable depreciations. However, the additional bonus that companies were in theory able to achieve by improving their quality of supply varied significantly between the companies and the observation years. Hence, the total economic effects of the investments were unpredictable, owing to the benchmarking methodology used. The effects of this example investment in different regulatory models are compared in Table 6.8.

Table 6.8. Comparison of the regulatory effects of the example investment.

Regulation model	-2005	2005–2007 (1st regulatory period)	2008–2011 (2nd regulatory period)
Effect of the investment to annual allowed incomes	+ 193 … 289 k€	+ 54 k€	+ 75 k€
Return on investment in the first year	35.5 … 54.7 %	7.7 %	11.9 %

As it can be seen, the return on investment was highest in the first regulation model, which was applied before year 2005. However, the model suffered from poor predictability, which is seen in the variation of the return on investment. The major differences in the models of the first and second regulatory periods are the quality adjustment and efficiency benchmarking. We can see that owing to these incentive mechanisms, higher returns are provided for the investment that improves the quality of supply.

6.3.4.2. Example 2: Replacing an overhead line with an underground cable

In this example, it is assumed that the same investment cost as in the previous example, 500 k€, is used to improve the quality of the supply. However, in this case, the strategy is to replace the overhead lines with underground cables, the depreciation time of which is 40 years. The length of the line to be replaced is 12 km, and the repurchase value of the existing overhead line is 250 k€. The age of the line is equal to the lifetime, so that the present value of the line in the regulatory calculations is zero. The decrease in the interruption time will be same as in the previous example, that is 1 800 customer,h, which is equal to the interruption costs of 40 k€. The decrease in the operational costs is assumed to be 2 k€.

The present value of the network will increase by 500 k€, similarly as in the previous example. However, since the existing network is replaced, the repurchase value is increased only by 250 k€, and thus the increase in the reasonable depreciation costs, that is, the annual straight-line depreciations calculated from the repurchase value will be 6.3 k€. Also the change in the actual depreciation costs is assumed to be equal to that. The total decrease in the input parameter of the efficiency benchmarking will be 35.7 k€, which will lead to a 0.5 percentage unit increase in the efficiency score, and hence to a 0.06 percentage unit decrease in the annual individual efficiency requirement, which will be equal to a 1.2 k€ increase in the allowed incomes. Since the overhead lines are replaced by underground cables, the network volume decreases by 0.04 % (see Eq. (4.8) in section 4.2.1). This will lead to a decrease of 0.9 k€ in the allowed incomes. The changes in the allowed profit and quality adjustment are equal to the previous example. The regulatory effects of the example investment in the new regulation model are presented in Table 6.9.

Table 6.9. Regulatory effects of the example investment in the new regulatory model.

Change in the allowed profit (in the 1st year after the investment)	+ 25 k€
Change in the reasonable depreciations (= straight-line depreciations)	+ 6.3 k€
Change in the reasonable operational costs that is due to the change in the individual efficiency requirement	+ 1.2 k€
Change in the reasonable operational costs that is due to the change in the network volume	- 0.9 k€
Change in the quality adjustment	+ 20 k€
Total effect on the allowed incomes (in the 1st year after the investment)	+ 51.6 k€
Return on investment in the first year = (increase in allowed incomes – increase in annual operational and depreciation expenses) / investment costs	9.5 %

As illustrated in the previous example, the allowed profit, reasonable depreciations, and network volume were determined similarly in the regulation model of the first regulatory period, that is, the years 2005–2007, as in the new model. Furthermore, efficiency benchmarking and quality adjustment were not included in that regulation framework. Hence, this example investment would have increased the allowed incomes by 30.4 k€ in the regulation model of the first regulatory period. This means that return on investment in that model would have been 5.2 %, as shown in Table 6.10.

Table 6.10. Regulatory effects of the example investment in the regulatory model applied in 2005–2007.

Change in the allowed profit (in the 1st year after the investment)	+ 25 k€
Change in the reasonable depreciations (= straight-line depreciations)	+ 6.3 k€
Change in the reasonable operational costs that is due to the change in the network volume	- 0.9 k€
Total effect on the allowed incomes (in the 1st year after the investment)	+ 30.4 k€
Return on investment in the first year = (increase in allowed incomes – increase in annual operational and depreciation expenses) / investment costs	5.2 %

In the model, which was used before year 2005, the reasonable depreciation costs were based on the three years' average of the investment costs. Hence, both an extension and a replacement investment have an equal effect in the model. The effect of the efficiency benchmarking is also quite similar to the previous example. The only difference is that the operational costs decrease in this example; the change is assumed to be -2 k€. Hence, the efficiency score would increase, owing to the decrease in the operational costs, by 0.09 percentage unit. The effect of the interruption time is similar as in the previous example: The efficiency score would have increased by 0–4.8 percentage unit, because of a 4 per cent decrease in interruption time. The total increase in the efficiency score would have varied between 0.09 and 4.89 percentage unit, while the decrease in the operational costs was 2 k€. These will together result to a -0.2–95.7 k€ effect on the allowed operational costs. The effects of this example investment in the regulatory model that was used before year 2005 are presented in Table 6.11.

Table 6.11. Regulatory effects of the example investment in the regulatory model applied before 2005.

Change in the allowed profit (in the 1st year after the investment)	+ 25 k€
Change in the reasonable depreciations (in the 1st year after the investment)	+ 167 k€
Change in the reasonable operational costs that is due to the efficiency benchmarking	- 0.2 … + 95.7 k€
Total effect on the allowed incomes (in the 1st year after the investment)	+ 191.8 … 287.8 k€
Return on investment in the first year = (increase in allowed incomes – increase in annual operational and depreciation expenses) / investment costs	37.5 … 56.7 %

The effects of this example investment in different regulation models are compared in Table 6.12.

Table 6.12. Comparison of the regulatory effects of the example investment.

Regulation model	-2005	2005–2007 (1st regulatory period)	2008–2011 (2nd regulatory period)
Effect of the investment to annual allowed incomes	+ 191.8 … 287.8 k€	+ 30.4 k€	+ 51.6 k€
Return on investment in the first year	37.5 … 56.7 %	5.2 %	9.5 %

When comparing these two investment examples, we may see that although the investment cost and the effect on the interruption costs are equal in both cases, the effect on the allowed incomes is different in the new model, as well as in the model that was used during the years 2005–2007. That is because the first of these examples is an extension investment, while in the second example the existing overhead line is replaced by an underground cable. Therefore, the effects on the reasonable depreciation costs and on the network volume are different in these cases. However, in the model that was applied before the year 2005, reasonable depreciations were based on the investment costs, and hence an extension investment and a replacement investment had similar effects on the allowed incomes. Therefore, the only differences in these two example investments in such a model were due to their different effects on the operational costs.

6.3.4.3. Example 3: Renewing the network

In this example, we study how replacing an old network component with an identical new component affects the allowed incomes. It is assumed that a 20-km-long overhead line, which is at the end of its lifetime, is replaced by a new identical line. The investment cost of the line is 435 k€, and there are no effects on the interruption or operational costs. In addition, since the components are replaced by identical ones, the repurchase value of the network and hence the straight-line depreciations remain the same. The network volume also remains the same.

In the new regulatory model, as well as in the model used during the years 2005–2007, the only change in the allowed incomes is due to the change in the present value of the network, which will be 435 k€. With the regulatory return of 5 %, the increase in the allowed profit will be 22 k€, that is, the allowed profit is equal to the regulatory rate of return. The effect on the allowed profit is similar also in the regulatory model, which was used before the year 2005. However, all the investments affected the reasonable depreciations in such a model. Hence, reasonable depreciations would have increased by the third of the investment costs, 145 k€. Consequently, this example investment would have increased the allowed incomes by 167 k€ in total, which means a 38.4 % return on investment. The effects of this example investment in different regulation models are compared in Table 6.13.

Table 6.13. Comparison of the regulatory effects of the example investment.

Regulation model	-2005	2005–2007 (1st regulatory period)	2008–2011 (2nd regulatory period)
Effect of the investment to annual allowed incomes	+ 167 k€	+ 22 k€	+ 22 k€
Return on investment in the first year	38.4 %	5 %	5 %

6.3.4.4. Example 4: Replacing the existing lines

In this example, it is assumed that a similar line as in the previous example is replaced by using identical components. The only difference is that in this case, the replacement has to be made in the middle of the lifetime, so that the remaining value of the existing line has to be written down in accounting. Hence, the regulatory asset base will increase only by a half of the investment cost. The investment cost in this case is equal to the previous example, 435 k€. However, the increase in the present value of the network is only half of this, 217.5 k€. Therefore, the increase in the allowed profit is 10.9 k€, and thus return on investment will be only 2.5 % in the new model, as well as in the model used during the years 2005–2007. However, in the regulatory model that was applied before year 2005, reasonable depreciations increased owing to all investments, and this increase would have been equal to the previous example. Hence, the total effect of the investment on the allowed incomes in that model would have been 155.9 k€. The effects of this example investment in different regulation models are compared in Table 6.14.

Table 6.14. Comparison of the regulatory effects of the example investment.

Regulation model	-2005	2005–2007 (1st regulatory period)	2008–2011 (2nd regulatory period)
Effect of the investment to annual allowed incomes	+ 155.9 k€	+ 10.9 k€	+ 10.9 k€
Return on investment in the first year	35.8 %	2.5 %	2.5 %

It can be seen that in the regulation models of 1st and 2nd regulatory period, it is clearly unfavourable for the companies to renew the network components in a situation where there is still technical economic lifetime left. However, in the regulation model, which was used before year 2005, the effects of the reasonable depreciations were dominant. Since these depreciations were determined based on the three years' average of the investment costs, every investment increased these annual regulatory depreciation costs by the third of its investment cost. Therefore, also the replacement investment of this kind, where the component is replaced in the middle of it's lifetime, was beneficial for the companies.

6.3.4.5. Conclusions on the example investments

Analyses of the profitability of the example investments, presented above, show that return on the investment may vary greatly between different investments and between different regulation models. Returns on example investments in different regulation models are illustrated in Table 6.15.

Table 6.15. Returns on example investments in the first year in different regulation models.

Investment \ Regulation model	-2005	2005–2007 (1st regulatory period)	2008–2011 (2nd regulatory period)
1. New back-up line	35.5 … 54.7 %	7.7 %	11.9 %
2. Cabling	37.5 … 56.7 %	5.2 %	9.5 %
3. Renewing the network	38.4 %	5 %	5 %
4. Replacing the existing lines	35.8 %	2.5 %	2.5 %

In the regulation model that was used before year 2005, strong incentives for all the investments were provided. Since reasonable depreciations were determined based on three years' investment costs, companies were entitled to collect the investment costs of every investment during three years as increased revenues. Theoretically, companies were also provided with an additional bonus for the investment, which improved the quality of supply, since the interruption time was included in the efficiency benchmarking. However, the effect of the interruption time on the efficiency score varied significantly between the companies and between the observation years. Hence, the amount of such a bonus was difficult to predict.

In the regulation model of the first regulatory period, the years 2005–2007, network volume correction was included in the determination of the reasonable operational costs. Based on the analysis presented above, the effect of the network volume on the allowed incomes seems to be significant. In the new regulation model, applied during the second regulatory period, quality adjustment and individual efficiency requirements are added to the regulation framework. It can be seen that in the new model, strong incentives are provided for quality improvements, since the profit of the investment is notably higher, if it increases the quality level. Obviously, quality deterioration is similarly penalised. However, the long-term effects of the quality adjustment are unclear, since it is not known how the decreased or increased interruption costs will affect the reference level of interruption costs in the future. Furthermore, the effect of the efficiency benchmarking turned out to be minor in the new regulation model, as has been shown also in the earlier analyses. In addition to previous, the last two analyses revealed that the regulation directs companies to renew their networks after their lifetime has expired. If the networks have to be rebuilt before the end of their lifetime, the cost allowances of the economic regulation are significantly lower.

6.4. Comparison with some European countries

The directing signals of the economic regulation have been studied in this thesis by a theoretical analysis and a case study of the Finnish regulatory model. However, to find out whether there are similarities in some other regulatory models and if similar analysis methodology can be applied when studying other models, the properties of the regulatory models applied in two other European countries, viz. Norway and the UK have been analysed. These two countries have been chosen since they are the ones having the longest experiences in Europe of regulating the power distribution industry. However, it should be noticed that only the major elements of the regulation have been considered, and the analysis of the regulatory models is not as comprehensive as it was in the case of the Finnish regulatory model.

6.4.1. Norway

According to Grammeltvedt (2003), pure profit regulation was used in Norway between the years 1991 and 1996. After that, incentive regulation, based on revenue cap has been used. From 1998 onwards, efficiency benchmarking has been a part of the regulatory model, as individual efficiency requirements have been determined by the DEA. The parameters of the DEA model, after the revision of the model in 2001, are presented in Table 6.16.

Table 6.16. Parameters of the old DEA model in the regulatory benchmarking used in Norway (Grammeltvedt 2003).

Inputs	Outputs	Environmental parameters
Number of man-labour years	Energy delivered	Network length
Net losses	Number of connections	Normalised interruption time
Net assets		
OPEX		
Interruption time		

Quality issues were included in the model in 2000, when the system of quality-dependent revenue caps was introduced. The basic idea of the quality incentive scheme is to compare the quality level of the company with the normalised quality level, and to increase or decrease the allowed revenue based on the difference of the actual and normalised quality level. The normalised quality level is based on the historic data and environmental factors. The cost of non-delivered energy is used as a quality indicator.

According to Sand et al. (2007), the regulation model has been changed from the beginning of 2007 so that the total revenue cap of the Norwegian distribution companies is equal to the total costs of the companies, and the norm cost, which is determined by the DEA benchmarking, is used to divide the revenue cap between the companies. The revenue cap of the distribution company is determined as shown in Equation (6.6) (Sand et al. 2007).

$$R_{i,t} = \alpha * C_{i,(t-2)} + (1-\alpha) * C_i^*, \tag{6.6}$$

where

$R_{i,t}$ = allowed revenue of the company i in year t

α = weighting factor

$C_{i,(t-2)}$ = costs of the company i in year t-2

C_i^* = norm cost of the company i

As Sand et al. (2007) have shown, costs include operational and maintenance costs, costs of customer management, cost of losses, depreciation costs, regulated return on assets, and costs of energy not supplied. The weighting factor α is 50 % for the years 2007 and 2008, and 40 % after that, so that the weight of the norm costs will increase. The norm costs are determined based on the DEA benchmarking, as presented in Equation (6.7) (Sand et al. 2007)

$$C_i^* = C_i * \frac{h_i}{h_{ave}}, \tag{6.7}$$

where

C_i^* = norm cost of the company i

C_i = actual cost of the company i

h_i = efficiency score of the company i, calculated by the DEA

h_{ave} = average efficiency score of all companies, calculated by the DEA

The methodology of the efficiency benchmarking in the new regulatory model has been changed so that a CRS model is used instead of the VRS model, and the only input parameter is total costs. In addition, changes in the output parameters have been made. The parameters of the new benchmarking model are presented in Table 6.17 (Foosnaes 2007).

Table 6.17. Parameters of the new DEA model in the regulatory benchmarking used in Norway (Foosnaes 2007).

Input	Outputs
Total costs	Length of the high-voltage network
	Energy delivered
	Number of substations
	Number of customers (divided into summer cottages and other customers)
	Interfaces to regional grid
	Climatic conditions (maximum wind in the distribution area)
	Depth of snow

A common characteristic for the Nordic countries is the quite large number of distribution companies. In Norway, the number of distribution companies is 150 (European Commission 2004). Hence, the regulatory models in both Finland and Norway are developed so that the regulatory decisions are based to transparent mechanical calculations. Although the negotiations between the companies and regulator are possible in these models, their role is generally minimal. Hence, the directing signals of the Norwegian regulatory model can be determined by a similar analysis as the one presented in the Finnish case.

The Norwegian regulation model and its development process have similarities with the Finnish ones. In the previous Norwegian model, interruption time was a separate parameter in the benchmarking, while in the new model, total costs are the only input parameter in the benchmarking. In addition, the returns-to-scale assumption is changed in both the Norwegian and Finnish models. However, in the Norwegian model, a CRS model is used, and thus the incentives for mergers are stronger than in the Finnish model. Furthermore, the Norwegian model is closer to yardstick regulation, and hence, efficiency benchmarking is used not only to derive the individual efficiency requirements, but also to introduce pseudo competition between the companies. This is because benchmarking is used to divide the total income cap between the companies, and thereby the situation is zero-sum game for the distribution companies. In this model, the allowed income of one company depends on the efficiency scores of all the companies. In the Finnish regulation model, benchmarking provides an efficiency requirement of a couple of per cents for the operational costs of the companies, while in the Norwegian model, approximately half of the allowed incomes of the distribution companies are determined based on the results of the benchmarking. Hence, such a model provides stricter requirements for the efficiency improvements, which in practice means stronger demands for the planning of the operational activities and network investments.

6.4.2. The United Kingdom

The business environment of the electricity distribution is quite different in the UK, when comparing it with the ones in Finland or Norway. The number of the distribution companies is 14, and some of these belong to the same owner, so that there are only nine company groups. According to OFGEM (2004), the allowed revenue, based on the estimates of operational and capital expenditures, financing costs, taxes, and the effects of the incentive schemes, is calculated for a five years' regulatory period. In addition, efficiency benchmarking is applied in the determination of the reasonable operational costs. Thus, the basic principle of the regulation seems somewhat similar to the Finnish model. However, if we consider the determination of the directing signals, there are significant differences in those models.

According to OFGEM (2004), efficiency benchmarking, based on the COLS (Corrected Ordinary Least Squares) method, is used in the process of determining the allowed operational costs. However, the reasonable OPEX is not based solely on the efficiency evaluation, but company-specific issues, such as a demanding operational environment or needs for tree cutting, are taken into account. The allowed capital costs for the upcoming regulatory period are based on the sliding scale mechanism, where the forecast of the company, as well as the view of the consultant that represents the regulator, are taken into account. Companies are provided with additional incomes, if their forecasts are close to the consultant's view, and also incentives for savings in the actual capital costs are given. Furthermore, additional costs allowances are granted to reach the power quality targets, to fulfil the environmental demands, such as undergrounding in the areas of the outstanding natural beauty, and to encourage such issues as corporate social responsibility.

Incentive schemes for quality, including the number and duration of interruptions, as well as quality of telephone services, are included in the regulatory framework. According to OFGEM (2004), interruptions have a symmetric and capped effect on the allowed revenue, so that the number of interruptions can increase or decrease the revenue by 1.2 per cent, and the maximum effect of the interruption time is 1.8 per cent. Announced and unannounced interruptions have different weights. Targets for the quality indices, as well as incentive rates are company specific. The incentive rate in this case is the monetary reward or penalty for quality performance. The estimation of the speed and quality of the telephone services is based on a customer survey, and the services in normal and storm conditions are separated. Telephone service in normal conditions has an asymmetric incentive scheme, so that the maximum penalty is 0.25 per cent, and the maximum award is only 0.05 per cent. Telephone response in storm conditions has a symmetric penalty and award so that the maximum effect on the allowed revenue is 0.25 per cent. In addition, there are incentive schemes for connecting distributed generation to the network as well as for development and research activities. In practice, partial pass-through is allowed for the costs of the development projects, as well as for the costs that are caused by providing the network access for distributed generation.

While determination of the allowed revenues is a fully mechanical process in the Finnish regulatory model, in the UK, the situation is quite different. There are multiple different incentive schemes, with company-specific targets and incentive rates. In addition, these schemes are related to company-specific cost allowances. Furthermore, there are issues such as an incentive scheme for development projects, where a part of the costs is treated as a pass-through cost item. Because of a small number of companies, negotiations between the companies and the regulator can be used as a part of the price control process. Hence, company-specific demands can be taken into account; however, the return on the investment is both case and company specific, and therefore, similar mechanical calculations for the profitability of the investment as presented in the Finnish case cannot be used.

6.5. Conclusions on the Finnish regulation

The development of Finnish regulatory benchmarking, illustrated in this thesis, has mostly been based on the analysis of the directing signals. The objective has been to develop the regulation and benchmarking so that they provide companies with directing signals that are in line with the common principles applied in the long-term planning of the distribution networks, that is, to minimise the total costs, including operational, capital, and interruption costs, during the lifetime of the network. The most suitable option, when considering the directing signals and practical implementation of the model, turned out to be using the sum of the straight-line depreciations, operational costs and interruption costs as the only input parameter in the benchmarking. Furthermore, the problem concerning the outliers, that is, the smallest and largest companies measured with a benchmarking parameter, was proposed to be solved by using the constant returns to scale (CRS) model instead of the VRS model. However, the EMA (2007a) decided to use the non-decreasing returns to scale (NDRS) model to compensate the assumed lower productivity of the small companies. The key features of the new Finnish regulation model are presented in Table 6.18.

Table 6.18. Key features of the Finnish regulatory model.

Time period	Major features of regulation and benchmarking
2008–2011 (Second regulatory period)	• Allowed profit = Present value of the network * WACC • Reasonable depreciation costs = straight-line depreciations (= repurchase value / lifetime) • Sum of the OPEX, interruption costs and straight-line depreciations as a single input parameter of the efficiency benchmarking • Two parallel benchmarking models (DEA and SFA) • Non-decreasing returns to scale assumption instead of variable returns to scale in the DEA • Reasonable OPEX based on the historic values and the general and individual efficiency requirements • Quality adjustment: allowed incomes are adjusted by the difference in the actual and reasonable interruption costs • Standard compensation costs (paid to the customers for interruptions over 12 hours) as controlled OPEX

Using the NDRS instead of the VRS model solved the outlier problems concerning the largest companies, but incentives for mergers of the small companies are significantly weaker than in CRS model, and hence, the companies are not encouraged to seek for the most optimal scale of operation. Furthermore, although including the capital costs in the benchmarking model improved its directing signals, there are still trade-off effects, since replacement investments do not affect the straight-line depreciations, calculated from the repurchase value of the network. In addition, the calculation methodology of the interruption costs has to be improved further, as the differences in the outage costs of the different customer types cannot be taken into account in the present methodology. Hence, although the development of the Finnish regulatory model has been going on for more than a decade, there are still improvement needs, and thus, the research and development work will continue also in the future.

In addition to the development of the DEA model, the regulator decided to develop an analogous efficiency benchmarking model, based on the SFA method, to be used to control the results of the DEA model. In practice, the individual efficiency requirement is calculated as an average of the efficiency score of the DEA and SFA models. Although using parallel benchmarking models increases the consistency of the benchmarking results, it also increases the complexity of the regulation model. Furthermore, although the directing signals of the regulation were improved by the development of the incentive schemes, the problem was the lack of long-term data on the quality of supply. Hence, the reference value of interruption costs could not be determined before the beginning of the regulatory period, and an error marginal was added to the efficiency requirement to compensate possible errors in the input data. This can be seen as a good practical lesson on the importance of the data collection process. In practice, this means that the gathering of uniform data has to be started as early as possible, in order to implement the incentive schemes in practice. This concerns especially the quality data, since annual variations in such data are usually high, and hence data from a period of several years are needed to compose a reliable interruption index that reflects the actual quality level of the company.

7. Concluding remarks

One of the major objectives of the restructuring process of the power supply industry of the 1990s and 2000s has been to increase the efficiency of the industry. In generation and supply, this is achieved by free competition. However, natural monopolies are found to be the most efficient form of production in the transmission and distribution of electricity, and therefore such companies have remained franchised monopolies. Economic regulation of the monopoly business is needed to prevent the misuse of the monopoly position and to guarantee the rights of the customers. In addition, to fulfil the objective concerning the efficiency improvements and to respond to the increasing demand for the quality of supply, regulators are including incentive schemes in the regulatory frameworks. To provide companies with efficiency and quality incentives, performance benchmarking is in many cases included in the regulatory framework. Since in such an approach, the outcomes of the regulation depend on the performance of the company, benchmarking tends to reshape the directing signals of the economic regulation. In addition, because electricity distribution is a capital-intensive business with long asset lifetimes, the network investments have long-lasting economic and technical effects. Furthermore, non-interrupted and cost-efficient electricity distribution is a vital element in the modern society. Hence, it is essential to ensure that economic regulation directs companies to design their networks and organisational structures so that the total socio-economic welfare is maximised.

In this thesis, the economic regulation and efficiency benchmarking of the electricity distribution companies are analysed from the viewpoint of the directing signals. The main statement of this thesis is that the development of the regulation and benchmarking model cannot be carried without considering the practical directing signals for regulated companies. Based on this finding, a method for analysing the directing signals of the regulatory benchmarking is developed. If the directing signals of the economic regulation are not analysed during the development of the model, the regulated companies may be provided with unintended incentives for network investments, which are not in line with the general principles of the network design, that is, minimising the total costs of the electricity distribution during the lifetime of the distribution network. The contributions of this thesis are:

1.) Novel analyses of the regulatory framework, so that the actual directing signals of the regulation and benchmarking for the electricity distribution companies is evaluated.

2.) Development of the methodology and a software tool for analysing the directing signals of the regulation and benchmarking.

3.) An analysis of the directing signals of the real-life regulatory frameworks by the methodology developed in the work. Based on these analyses, proposals for regulatory development have been made.

7.1. Directing signals of the regulation and benchmarking

In the economic literature, the directing signals of the incentive regulation and performance benchmarking are typically studied by an analysis of the principal-agent problem, where the regulated company is assumed an agent and regulator a principal, and the regulation model is described as contract between the principal and the agent. However, these analyses are characterised by a mainly theoretical viewpoint, and usually they do not consider the characteristics of the specific industry. In this thesis, industry-specific studies about the directing signals of the performance measurement are carried out by analysing the regulatory benchmarking of the electricity distribution companies. In particular, issues such as choosing the parameters included in the performance benchmarking, the characteristics of the benchmarking method, and the methodology used to apply the results to the regulatory calculations, are found to be highly relevant from the viewpoint of the directing signals.

The directing signals of the regulation may reflect on the investment strategies and the organisational development of the distribution companies. For instance, when the quality of supply is included in the economic regulation, the interruption costs, incurred by customers, are internalised in the economy of the company. Hence, in such a case, companies are incentivised to take also the interruption costs into account during the design of the networks and planning of the maintenance actions. In addition to power quality, the role of capital costs in the regulation and benchmarking has significant effects on the directing signals. If the capital costs are excluded from the benchmarking process, companies benefit from the trade-offs between the operational or interruption costs and capital costs. Such a distorted directing signal has an effect that companies may optimise their business processes and maintenance strategies to maximise the regulatory allowed profit, instead of minimising the total costs. In addition, choosing the returns-to-scale assumption, as an example of the characteristics of the benchmarking methodology, has effects on the profitability of the mergers and the efficiency incentives of the outliers. However, the directing signals are not only dependent on the parameters and methodology of benchmarking, but the economic effects of benchmarking are also strongly dependent on the role of benchmarking in the regulatory framework. Hence, a benchmarking model cannot be designed as a separate part of the regulation model, but the role of the benchmarking in the regulatory framework has to be taken into account.

In the analysis about the real-life effects of the regulation, correlations between the changes in the regulatory framework and distribution pricing have been found. It seems that companies adjust their pricing as the regulation model changes, but price adjustments tend to be higher than the demands of the regulator. Furthermore, it has been found that the investment levels of the distribution companies do not correlate with the kind of high investment incentives of the Finnish regulation model, which may result form the uncertainty in the business environment.

7.2. Method for analysing the directing signals

To find the actual directing signals of the regulation and benchmarking, it does not suffice to analyse the effects of the input parameters on the efficiency score, but also the effects of the efficiency score on the allowed incomes have to be taken into account. Furthermore, other economic effects of the input parameters, such as effects on the regulatory asset base, have to be simultaneously taken into account. This way, the total effects of input parameters on the outcomes of the regulatory calculations, that is, the marginal price of a parameter, can be found. In this thesis, methodology for such an analysis has been developed, and it has been implemented in a software tool in order to perform such an analysis in practice.

The basic principle of this tool is to run simulations, where the input data is changed as defined by the user, and the effects of this data variation to the regulatory allowed incomes of the companies are calculated. There can be one or more parameters, which are changed simultaneously, and these changes can be done for one or all companies. Hence, it is possible to analyse the effects of a single benchmarking parameter, as well as to run a case study concerning a certain network investment, where multiple parameters are changed simultaneously. The analysis may concentrate on a single company, or the average effects of all the companies can be determined. In addition, it is possible to analyse how the data changes of the peer companies affect the allowed incomes of the inefficient companies. In this software tool, efficiency scores are calculated by the DEA method, but a similar approach can also be used with other benchmarking methods. This tool has been applied during the analysis and development of the Finnish regulatory framework. In addition to the regulatory development, such a tool is useful for distribution companies, since they can apply it for instance to analyse the effects of certain network investment on the regulatory allowed incomes.

7.3. Development of the regulatory benchmarking

The analysis methodology and the tool, described above, has been applied in practice during the analysis and development of the Finnish regulatory benchmarking. The key issues in this development process have been the analysis of the role of the power quality and the capital costs in the efficiency benchmarking, and the evaluation of the returns to scale assumptions from the directing signals' viewpoint. In the former benchmarking model, power quality was measured as interruption time and included in the VRS DEA benchmarking as a non-controllable input parameter. Furthermore, capital costs were not included in the benchmarking process.

In order to provide clear and stable directing signals, the marginal price of the benchmarking parameters have to be stable and predictable for the regulated companies. Otherwise, companies cannot foresee the economic effects of the network investments or maintenance actions. During the analysis, it has been found that if there are multiple input parameters in the DEA benchmarking, the individual weight for each parameter is determined, and these weights can vary greatly between the companies and between the observation years. Furthermore, these weights reflect theoretically the technological possibilities for trade-offs between these input parameters. However, to ensure that regulation provides incentives for maximising total socio-economical welfare, the marginal price of interruptions should be equal to the welfare loss of the customers because of the interruptions. Hence, the most suitable solution turned out to be to measure power quality as interruption costs, where both the number and duration of interruptions are taken into account and interruptions are categorised to short and long interruptions, as well as announced and unannounced ones. These interruption indices are weighted by the welfare losses of the customer, which are due to such interruptions.

Furthermore, in this case, straight-line depreciations, calculated from the repurchase value of the distribution network, were seen as the most suitable indicator of the annual capital costs. Hence, in the developed benchmarking model, the sum of the operational costs, interruption costs and annual straight-line deprecations formed a single input parameter. Such a benchmarking model provides companies with incentives to minimise the total costs of the electricity distribution, including also cost incurred by the customers because of interruptions. During the analysis, it has also been found that the efficiency incentives of the outlier companies can be improved by using the constant returns to scale (CRS) model instead of the variable returns to scale (VRS). In addition to these, during the practical development of the model, it has been found that it is essential to start collecting the performance data several years before implementing any incentive schemes in practice. These research results have played a key role in the development of the benchmarking model, which is nowadays used by the Finnish regulator as a part of the economic regulation of the electricity distribution companies.

7.4. Future work

Although the development process of the Finnish regulatory framework has been continuing for several years, there are still development needs in the model, and therefore this work will continue also in the future. In addition, the thesis has concentrated on the evaluation of the directing signals of the regulatory framework, yet the actual effects of these signals on the distribution networks, for instance network topology or preferred components, are not considered in a large scale. Hence, an evaluation of the regulatory effects on the long-term planning of distribution networks would be an interesting research topic in the future.

A key concern during the development process of the efficiency benchmarking has been to improve the directing signals of the economic regulation. However, there remains an interesting question how the role of the benchmarking in the regulatory framework will be changing in the future. That is, whether the primary objective of the benchmarking will be to decrease the efficiency differences of the companies or to introduce pseudo competition to the monopoly sector, or will benchmarking be used as an informal proofing tool to ensure that the efficiency of the companies will improve as expected. From this viewpoint, an obvious future research topic will be to investigate the needs and role of benchmarking in the future regulatory framework.

References

Agrell, P., Bogetoft, P. and Tind, J. 2000. Multi-period DEA Incentive Regulation in Electricity Distribution. Discussion Paper 2000-13. Centre for Industrial Economics, University of Copenhagen.

Ajodhia, V. and Hakvoort, R. 2005. Economic regulation of quality in electricity distribution networks. Utilities Policy 13. 211–221.

Ajodhia, V., Lo Schiavo, L., and Malaman, R. 2006. Quality regulation of electricity distribution in Italy: an evaluation study. Energy Policy 34. 1478–1486.

Allen, R., Athanassopoulos, A., Dyson, R. G., and Thanassoulis, E. 1997. Weight restrictions and value judgments in Data Envelopment Analysis: Evolution, development and future directions. Annals of Operations Research 73. 13–34.

Anderson, T., R. and Sharp, G. P. 1997. A new measure of baseball batters using DEA. Annals of Operations Research 73. 141–155.

Banker, R. D., Charnes, A., and Cooper, W. W. 1984. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. Management Science 30. 1078–1092.

Biewald, B., Woolf, T., Bradford, P., Chernick, P., Geller, S., and Oppenheim, J. 1997. Performance-Based Regulation in a Restructured Electric Industry. Synapse Energy Economics.

Bogetoft, P. 1994. Incentive Efficiency Production Frontiers: An Agency Perspective on DEA. Management Science 40:8. 959–968.

Bogetoft, P. 1995. Incentives and productivity measurements. International Journal of Production Economics 39. 67–81

Bogetoft, P. 1997. DEA-based yardstick competition: The optimality of best practice regulation. Annals of Operations Research 73. 277–298.

Bogetoft, P. 2000. DEA and Activity Planninig under Assymmetric Information. Journal of Productivity Analysis 13. 7–48.

Burns, P., Jenkins, C., and Riechmann, C. 2005. The role of benchmarking for yardstick competition. Utilities Policy 13. 302–309.

Burns, P., Turvey, R., and Weyman-Jones, T. G. 1998. The behaviour of the firm under alternative regulatory constraints. Scottish Journal of Political Economy 45:2. 133–157

Burns, P. and Weyman-Jones, T. G. 1996. Cost Functions and Cost Efficiency in Electricity Distribution: A Stochastic Frontier Approach. Bulletin of Economic Research 48:1. 41–64.

CEPA 2003. Background to Work on Assessing Efficiency for the 2005 Distribution Price Control Review. Cambridge Economic Policy Associates.

Charnes, A., Cooper, W.W., Lewin, A.Y., and Seiford, L.M. 1994. Data Envelopment Analysis: Theory, methodology and applications. Boston: Kluwer Academic Publishers.

Charnes, A., Cooper, W. W., and Rhodes, E. 1978. Measuring the efficiency of decision making units. European Journal of Operational Research 2. 429–444.

Coelli, T., Crespo, H., Perelman, S., Plagnet, M. A., and Romano, E. 2007. Incorporating Quality of Service in a Benchmarking Model: An Application to French Electricity Distribution Operators. Proceedings of the CIRED 2007, International Conference on Electricity Distribution, Vienna, Austria.

Coelli, T., Estache, A., Perelman, S., and Trujillo, L. 2003. A Primer on Efficiency Measurement for Utilities and Transport Regulators. Washington D.C., U.S.A.: World Bank Institute.

Coelli, T., Rao, P., O'Donnell, C., and Battese, G. 2005. An Introduction to Efficiency and Productivity Analysis - Second Edition. New York: Springer Science + Business Media.

Cooper, W. W., Seiford, L. M., and Tone, K. 2002. Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software. Norwell, Massachusetts: Kluwer Academic Publishers.

Electricity Market Act 386/1995 (Finish Electricity Market Act 386/1995; amendments up to 1172/2004 included)

EMA 1999. Päätös Megavoima Oy:n sähkön siirron hinnoittelun kohtuullisuudesta (Decision on the reasonableness of the pricing of Megavoima Oy). Sähkömarkkinakeskus. Dnro 182/42/95. (In Finnish). [Available online at www.energiamarkkinavirasto.fi, September 13, 2007]

EMA 2000. Sähkömarkkinakeskuksen vuosikertomus 1999 (Annual Report of Electricity Market Authority 1999). (In Finnish, with an English summary). [Available online at www.energiamarkkinavirasto.fi, October 1, 2007]

EMA 2001. Summary: Considerations of efficiency in the assessment of the reasonableness of electricity distribution pricing. The Finnish Energy Market Authority's Publications. [Available online at www.energiamarkkinavirasto.fi, September 13, 2007]

EMA 2003. Päätös Helsingin Energian sähkön siirron hinnoittelun kohtuullisuudesta vuosina 1997-2002. (Decision on the reasonableness of distribution pricing of Helsingin Energia in years 1997–2002). Energiamarkkinavirasto, Dnro 18/421/99. (In Finnish) [Available online at www.energiamarkkinavirasto.fi, September 13, 2007]

EMA 2004. Guidelines for assessing reasonableness in pricing of electricity distribution network operations for 2005–2007. The Finnish Energy Market Authority's publication. [Available online at www.energiamarkkinavirasto.fi, September 13, 2007]

EMA 2007a. Sähkön jakeluverkkotoiminnan hinnoittelun kohtuullisuuden arvioinnin suuntaviivat vuosille 2008–2011. (Guidelines for assessing reasonableness in pricing of electricity distribution network operations for 2008–2011). Energiamarkkinavirasto, Dnro 154/422/2007. (In Finnish). [Available online at www.energiamarkkinavirasto.fi, September 17, 2007]

EMA 2007b. Kalvokuvia sähkön hinnasta 1.9.2007. (Figures about the prices of electricity, September 1, 2007). (In Finnish). [Available online at www.energiamarkkinavirasto.fi, September 27, 2007]

EMA 2007c. Vuoden 2005 aikana kertyneet sähköverkkotoiminnan tuoton yli- ja alijäämät. (Surpluses and shortfalls in the profits of the electricity distribution companies in the year 2005). Press release of the Electricity Market Authority. January 12, 2007. (In Finnish). [Available online at www.energiamarkkinavirasto.fi, September 27, 2007]

EMA 2007d. Accounting records of Finnish electricity distribution companies. [Available online at www.energiamarkkinavirasto.fi, November 27, 2007]

EMA 2007e. Sähköverkkotoimintaan sitoutuneen pääoman kohtuulliset kustannusprosentit vuosille 2005–2007. (Reasonable return on capital for electricity distribution companies for the years 2005–2007). (In Finnish). [Available online at www.energiamarkkinavirasto.fi, December 21, 2007]

Emrouznejad, A. 2001. An Extensive Bibliography of Data Envelopment Analysis (DEA), Volumes I–V. Business School, University of Warwick. [Available online at www.deazone.com/bibliography, June 17, 2007]

ET 2007. Keskeytystilasto 2006. (Interruption statistics 2006 by Finnish Energy Industries). Energiateollisuus ry. Helsinki. (In Finnish). [Available online at www.energia.fi, October 1, 2007]

European Commission. 1996. Directive 96/92/EC. Official Journal of the European Union, No L 027. Brussels.

European Commission. 2003. Directive 2003/54/EC. Official Journal of the European Union, No L 176. Brussels.

European Commission. 2004. Technical Annexes to the Report from the Commission on the Implementation of the Gas and Electricity Internal Market. Brussels

Farrell, M., J. 1957. The Measurement of Productive Efficiency. Journal of the Royal Statistical Society. 120:3. 253–290.

Filippini, M. 1998. Are Municipal Electricity Distribution Utilities Natural Monopolies? Annals of Public and Cooperative Economics 69:2, 157–174

Foosnaes, A. H. 2007. Nettregulering i en nordisk kontekst (Network regulation in Nordic context). Master thesis. Norges Tekniske og Vitenskapelige Universitet. (In Norwegian, with an English summary)

Giannakis, D., Jamasb, T., and Pollitt, M. 2005. Benchmarking and incentive regulation of quality of service: an application to the UK electricity distribution networks. Energy Policy 33. 2256–2271.

González, J. P. P. 2004. A Reference Network Model: the PECO model. Working Paper IIT-04-029A.

Grammeltvedt, T. E. 2003. DEA-Analysis – Can they be used in Regulation? Pros and Cons from Five Years' Experiences in Norway. Proceedings – Proceedings of the Market Design 2003 Conference. Stockholm.

Grenard, S. and Strbac, G. 2003. Effect of Regulation on Distribution Companies Investment Policies in the UK. IEEE Bologna PowerTech Conference, Bologna, Italy.

Growitsch, C., Jamasb, T., and Pollitt, M. 2005. Quality of Service, Efficiency, and Scale in Network Industries: An Analysis of European Electricity Distribution. Cambridge Working Papers in Economics 0538. University of Cambridge.

Gunn, C. and Sharp, B. 1999. Electricity distribution as an unsustainable natural monopoly: a potential outcome of New Zealand's regulatory regime. Energy Economics 21, 385–401.

Hakvoort, R. 2000. Technology and Restructuring the Electricity Market. International Conference on Electric Utility Deregulation and Restructuring and Power Technologies 2000. London. England.

Halme, M., Joro, T., Korhonen, P., Salo, S., and Wallenius, J. 1999. A Value Efficiency Approach to Incorporating Preference Information in Data Envelopment Analysis. Management Science 45:1. 103–115.

Honkapuro, S. 2002. Verkkoliiketoiminnan tehokkuusmittauksen ohjausvaikutusten analysointijärjestelmä. (Computing system for analysing the effects of the benchmarking of the electricity distribution companies). Master's Thesis. Lappeenranta, Finland. (In Finnish). [Available online at www.lut.fi, April 9, 2008]

Honkapuro, S., Lassila, J., and Partanen, J. 2006a. Software application for analysing the efficiency benchmarking of the electricity distribution companies. Proceedings of the PEA 2006, Power, Energy and Applications, Gaborone, Botswana.

Honkapuro, S., Lassila, J., and Partanen, J. 2006b. Efficiency targets in economic regulation and their impact on the development of electricity distribution business. Proceedings of the CIDEL 2006, International Congress on Electricity Distribution, Buenos Aires, Argentina.

Honkapuro, S., Lassila, J., Viljainen, S., Tahvanainen, K., and Partanen, J. 2004a. Effects of benchmarking of electricity distribution companies in Nordic countries – comparison between different benchmarking methods. Proceedings of the NORDAC 2004, Nordic Distribution and Asset Management Conference, Espoo, Finland.

Honkapuro, S., Lassila, J., Viljainen, S., Tahvanainen, K., and Partanen J. 2004b. Econometric model as a regulatory tool in electricity distribution – Case Network Performance Assessment Model. Research report. Lappeenranta. [Available online at www.lut.fi, June 19, 2007]

Honkapuro, S., Lassila, J., Viljainen, S., Tahvanainen, K., and Partanen, J. 2005. Regulatory Effects on the Investment Strategies of Electricity Distribution Companies. Proceedings of the CIRED 2005, International Conference on Electricity Distribution, Turin, Italy.

Honkapuro, S. and Partanen, J. 2006. Efficiency benchmarking in the economic regulation of the distribution companies. Proceedings of the NORDAC 2006, Nordic Distribution and Asset Management Conference, Stockholm, Sweden.

Honkapuro, S., Tahvanainen, K., Viljainen, S., Lassila, J., Partanen, J., Kivikko, K., Mäkinen, A., and Järventausta, P. 2006c. DEA-mallilla suoritettavan tehokkuusmittauksen kehittäminen. (Further development of the efficiency measurement model based on the DEA method). Research report. (in Finnish). [Available online at www.energiamarkkinavirasto.fi, August 9, 2007]

Honkapuro, S., Viljainen, S., and Partanen, J. 2007. Incentives and Obstacles of Implementing Efficiency Benchmarking in Economic Regulation. Proceedings of the CIRED 2007, International Conference on Electricity Distribution, Vienna, Austria.

Honkatukia, J. and Sulamaa, P. 1999. Tekninen tehokkuus ja kokonaistuottavuus Suomen sähkönjakeluverkkotoiminnassa 1996–1998. (Technical Efficiency and Total Factor Productivity in Finnish Electricity distribution 1996–1998). ETLA, The Research Institute of the Finnish Economy. Discussion Papers 692. (In Finnish, with an English abstract). [Available online at www.energiamarkkinavirasto.fi, September 13, 2007]

IEEE 2004. 1366-2003. IEEE Guide for Electric Power Distribution Reliability Indices. New York: The Institute of Electrical and Electronics Engineering.

Jamasb, T., Nillesen, P., and Pollit, M. 2003. Gaming the Regulator: A Survey. The Electricity Journal. December 2003. 68–80.

Jamasb, T., Nillesen, P., and Pollit, M. 2004. Strategic behaviour under regulatory benchmarking. Energy Economics 26. 825–843

Jamasb, T. and Pollitt, M. 2000. Benchmarking and Regulation of Electricity Transmission and Distribution Utilities: Lessons from International Experience. University of Cambridge.

Jamasb, T. and Pollitt, M. 2001. Benchmarking and Regulation: International Electricity Experience. Utilities Policy 9. 107–130.

Jamasb, T. and Pollitt, M. 2003. International benchmarking and regulation: an application to European electricity distribution utilities. Energy Policy 31. 1609–1622.

Joro, T. and Viitala, E-J. 1999. The Efficiency of Public Forestry Organizations: A Comparison of Different Weight Restriction Approaches. Interim Report IR-99-059. International Institute for Applied System Analysis.

Joskow, P. L. 2006. Incentive Regulation in Theory and Practice: Electricity Distribution and Transmission Networks. Massachusetts Institute of Technology

Järventausta, P., Mäkinen, A., Nikander, A., Kivikko, K., Partanen, J., Lassila, J., Viljainen, S., and Honkapuro, S. 2003. Sähkönlaatu jakeluverkkotoiminnan arvioinnissa (The role of power quality in the regulation of electricity distribution business). Publications of the Energy Market Authority, 1/2003. Helsinki, Finland. (In Finnish). [Available online at www.energiamarkkinavirasto.fi, December 3, 2007]

Kariuki, K. and Allan, R. 1996. Factors affecting customer outage costs due to electric service interruptions. IEE Proceedings of Generation, Transmission and Distribution, 143:6. 521–528.

Kinnunen, K. 2006. Investment incentives: regulation of the Finnish electricity distribution. Energy Policy 34. 853–862

Kivikko, K., Antila, S., Järventausta, P., Mäkinen, A., Lassila, J., Viljainen, S., Tahvanainen, K., Partanen, J., Mogstad, O., and Tapper, M. 2005a. Comparison of Interruption Statistics and Their Use in Network Business Regulation in Nordic Countries. Proceedings of the CIRED 2005, International Conference on Electricity Distribution, Italy.

Kivikko, K., Järventausta, P., Mäkinen, A., Eklund, T., Lehtomäki, E., Alasalmi, O., Isoviita, T., and Vainiola, K. 2005b. Developing of Compilation of Interruption Statistics in Finland to Meet Various New Requirements. Proceedings of the CIRED 2005, International Conference on Electricity Distribution, Italy.

Korhonen, P. and Syrjänen, M. 2003. Evaluation of Cost Efficiency in Finnish Electricity Distribution. Annals of Operations Research 121. 105–122.

Korhonen, P., Syrjänen, M., and Tötterström, M. 2000. Sähkönjakeluverkkoliiketoiminnan kustannustehokkuuden mittaaminen DEA-menetelmällä. (Assessment of Cost Efficiency in Finnish Electricity Distribution Using DEA). Publications of the Energy Market Authority, 1/2000. Helsinki. Finland. (In Finnish). [Available online at www.energiamarkkinavirasto.fi, September 13, 2007]

Künneke, R. W. 1999. Electricity networks: how 'natural' is the monopoly? Utilities Policy 8, 99–108.

Laffont, J. and Tirole, J. 1988. The dynamics of incentive contracts. Econometrica 56:5. 1153–1175.

Lakervi, E. and Holmes, E.J. 1995. Electricity distribution network design – 2nd edition. IEE Power Engineering Series 21. London, U.K.: Peter Peregrinus Ltd.

Larsson, M. B-O. 2005. The Network Performance Assessment Model, A new framework of regulating the Electricity Network Companies. Licentiate thesis, KTH, Sweden.

Lassila J., Honkapuro S., and Partanen J. 2005a. Economic Analysis of Outage Costs Parameters and Their Implications on Investment Decisions. Proceedings of the IEEE PES 2005 General Meeting, USA.

Lassila J., Honkapuro S., Viljainen S., Tahvanainen K., Partanen J., Kivikko K., Antila S., Mäkinen A., and Järventausta P. 2005b. Power Quality Factors in Efficiency Benchmarking. Proceedings of the CIRED 2005, International Conference on Electricity Distribution, Turin, Italy.

Lassila, J., Viljainen, S., Honkapuro, S., and Partanen, J. 2003a. Data Envelopment Analysis in the Benchmarking of Electricity Distribution Companies. Proceedings of the CIRED 2003, International Conference on Electricity Distribution, Barcelona, Spain.

Lassila, J., Viljainen, S., Honkapuro, S., and Partanen, J. 2003b. Verkkoliiketoiminnan tehokkuusmittauksen kehittäminen (Development of the benchmarking method of the electricity distribution). Research report. Lappeenranta (In Finnish). [Available online at www.lut.fi, November 20, 2007]

Lassila, J., Viljainen, S., and Partanen, J. 2002. Analysis of the benchmarking results of the electricity distribution companies in Finland. Proceedings of the IEEE Postgraduate Conference on Electric Power Systems. Budapest, Hungary.

Nelson, R., A. and Primeaux, W., J., Jr. 1988. The Effects of Competition on Transmission and Distribution Costs in the Municipal Electricity Industry. Land Economics. 64:4. 338–346.

Nemesys. 2005a. System Analysis, NEMESYS Subproject A. Final Report. Sumicsid Ab.

Nemesys. 2005b. Regulatory Mechanisms Design, NEMESYS Subproject B. Final Report. Sumicsid AB.

Nemesys. 2005c. Nordic Efficiency Model, NEMESYS Subproject C. Final Report. Sumicsid AB.

OFGEM 2004. Electricity Distribution Price Control Review: Final Proposal. Office of Gas and Electricity Markets. [Available online at http://www.ofgem.gov.uk, November 30, 2007]

Olson, W. and Richards, C. 2003. It's All in the incentives: Lessons Learned in Implementing Incentive Ratemaking. The Electricity Journal. December 2003. 20–29.

Pahwa, A., Feng, X., and Lubkeman, D. 2002. Performance Evaluation of Electricity Distribution Utilities Based on Data Envelopment Analysis. IEEE Transactions on Power Systems, vol. 17, no. 3, August.

Paradi, J. C., Reese, D. N., and Rosen, D. 1997. Applications of DEA to measure the efficiency of software production at two large Canadian banks. Annals of Operations Research 73. 91–115.

Partanen, J., Lassila, J., and Viljainen, S. 2002. Investoinnit sähkön siirron hinnoittelussa. (Investments in distribution pricing). Publications of the Energy Market Authority, 1/2002. Helsinki, Finland. (In Finnish). [Available online at www.energiamarkkinavirasto.fi, October 2, 2007]

Partanen, J., Lohjala, J., Kaipia, T., Rissanen, A., Lassila, J., Lahti, K., and Kärnä, A. 2005a. 20/1/0.4 kV three voltage level distribution system. Research report. Lappeenranta. [Available online at www.lut.fi, August 27, 2007]

Partanen, J. Viljainen, S., Lassila, J., Honkapuro, S., and Tahvanainen, K. 2004. Investoinnit verkkoliiketoiminnan valvonnassa – erityisesti tehokkuusmittauksessa. (Investments in regulation – especially in efficiency benchmarking). Publications of the Energy Market Authority, 1/2004. Helsinki, Finland. (In Finnish). [Available online at www.energiamarkkinavirasto.fi, October 2, 2007]

Partanen, J. Viljainen, S., Lassila, J., Honkapuro, S., Tahvanainen, K., Järventausta, P., Mäkinen, A., and Kivikko, K. 2005b. Power Quality Regulation from an Economical and a Technical Point of View. Proceedings of the Market Design 2005 – Conference on Security of Supply in Competitive Electricity Markets. Stockholm, Sweden.

Pedraja-Chaparro, F., Salinas-Jimenez, J., and Smith, P. 1999. On the quality of the data envelopment analysis model. Journal of the Operational Research Society. 50. 636–644.

Ramos-Real, F., J. 2005. Cost functions and the electric utility industry. A contribution to the debate on deregulation. Energy Policy 33, 69–87.

Rivier, J. and Gómez, T. 2000. A Conceptual Framework for Power Quality Regulation. 9th international conference on Harmonics and Quality of Power. October 1–4. Orlando, Florida, USA.

Sand, K., Storset, K., Samdal, K., and Nordgård, D.E. 2007. Distribution Network Operator Regulation – A Task-oriented Approach. Proceedings of the CIRED 2007, International Conference on Electricity Distribution, Vienna, Austria.

Shuttleworth, G. 2005. Benchmarking of electricity networks: Practical problems with its use for regulation. Utilities Policy. 13. 310–317.

Simar, L. and Wilson, P. W. 2000. Statistical Interface in Nonparametric Frontier Models: The State of the Art. Journal of Productivity Analysis 13. 49–78.

Silvast, A., Heine, P., Lehtonen, M., Kivikko, K., Mäkinen, A., and Järventausta, P. 2005. Sähkönjakelun keskeytyksestä aiheutuva haitta (Costs of electricity supply outages). Research Report. Helsinki University of Technology. (In Finnish, with an English summary) [Available online at http://powersystems.tkk.fi, November 22, 2007]

Statistics Finland. 2007. Tilastokeskuksen kuluttajahintaindeksi (Consumer Price Index by Statistics Finland). (In Finnish). [Available online at www.stat.fi, September 28, 2007]

Syrjänen, M. Bogetoft, P., and Agrell, P. 2006. Efficiency benchmarking project B: Analogous efficiency measurement model based on Stochastic Frontier Analysis. Final Report. [Available online at www.energiamarkkinavirasto.fi, June 18, 2007]

Talouselämä 2007. Sähköyhtiöt tekevät rahaa helposti. (Electricity companies earn money easily) Talouselämä 16 May 2007. Talentum. (in Finnish)

Ter-Martirosyan, A. 2003. The Effects of Incentive Regulation on Quality of Service in Electricity Markers. Working Paper. George Washington University.

Vickers, J. and Yarrow, G. 1988. Privatization: An Economic Analysis. London, England. The MIT Press.

Viljainen, S. 2005. Regulation design in the electricity distribution sector – theory and practice. Dissertation, Lappeenranta University of Technology.

Vogelsang, I. 2002. Incentive Regulation and Competition in Public Utility Markets: A 20-Year Perspective. Journal of Regulatory Economics. 22:1. 5–27.

Wallnerström C. J. and Bertling, L. 2007. A Sensitivity Study of the Swedish Network Performance Assessment Model Investigating Effects of Changes in Input Data. Proceedings of the CIRED 2007, International Conference on Electricity Distribution, Vienna, Austria.

Yatchew, A. 2000. Scale Economies in Electricity Distribution: A Semiparametric Analysis. Journal of Applied Econometrics. 15. 187–210.

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