Will Grid Investment under Regulatory Benchmarking be Sustainable?

Christoph Weber und Dominik Schober
Chair of Management Science and Energy Economics
University of Duisburg-Essen (Campus Essen)
Universitätsstr. 11
45117 Essen

phone: 0049-(0)201-183-2966
0049-(0)201-183-2903
Christoph.Weber@uni-duisburg-essen.de; Dominik.Schober@uni-duisburg-essen.de

JEL-Classification: L51, L52
Keywords: Electricity markets, regulation, benchmarking, sustainability, networks, heterogeneous capital structures

Abstract

Formerly developed for management purposes, benchmarking has also become increasingly interesting for regulatory purposes.

After an overview of the existing benchmarking methods and problems associated with benchmarking we turn to an important but in the current research widely ignored aspect, the influence of investment cycles and thereof resulting heterogeneous capital structures of grid operators on investment incentives in the benchmarking process.

In this article we use an analytical model to examine the different channels of influence of heterogeneous capital structures in a step-by-step approach to clarify the relevance of capital structure heterogeneity.

As a reference case, we first analyse a homogeneous capital good. We derive the conventional wisdom rule that amortization periods should correspond to average lifetime of capital goods and show that under this condition benchmarking will not lead to sustainability problems.

In a second step we investigate the case of heterogeneous capital stock with capital vintages, assuming a constant life cycle of the capital goods. As in the first case it can be shown that benchmarking is feasible without difficulties concerning long-term sustainability of grid investments.

Finally we consider a heterogeneous capital stock with non-constant lifetime. A major finding is that under these conditions a straight benchmarking approach among firms with heterogeneous capital vintage structure will result in setting a benchmark, which will lead to significant sustainability problems.

1 Introduction

After formal liberalisation of the German Electricity and Gas Market in 1998, the public and politicians remained dissatisfied with the lack of competition and the remaining monopolistic structures.

In 2005 the German Regulator (Bundesnetzagentur) was assigned to develop a workable concept for an incentive regulation of the German Energy Market on the basis of the second amendment of the German Energy Law (“Energiewirtschaftsgesetz (EnWG)”).[1]

The development of active and direct competition is hindered by the monopolistic bottleneck character of the infrastructure.[2] Consequently, the regulator has to create mechanisms, which induce the necessary pressure on costs and prices indirectly. The extensive literature shows that this goal can hardly be achieved with the currently applied cost plus regulation.[3]

Alternatively, there exist numerous forms of incentive based regulation schemes.[4] The *RPI-X*-regulation primarily developed by Littlechild (1983) is the dominant incentive scheme among the incentive based regulation methods. They induce the necessary pressure on prices and costs by trying to decouple prices or revenues of a regulated entity from its costs. The regulator will particularly prescribe prices (price-cap regulation) or revenues (revenue-cap regulation) adapted to the expected inflation on the one and the expected productivity gain on the other hand.[5]

The application of benchmarking techniques plays an important role for the determination of the *X*-factor in an *RPI-X*-regulation. Jamasb/Nillesen/Pollitt (2004) explain benchmarking “*as the comparison of a firm’s actual performance against some predefined reference or benchmark performance*.”[6] These comparisons of firms serve to determine efficiency rankings which thereafter can be translated into targets for the productivity gain (*X*-factor). Berg et al. give a good overview of the different methods in their study for the World Banc.[7] An important distinction of benchmarking methods is the one between the “frontier”- (efficiency frontier methods) and the “non-frontier”-methods (average methods). A special form of the *RPI-X*-regulation is the yardstick regulation which is at the same time the regulation scheme en-

---

[1] EnWG, 13th of July 2005. §112a set a respite by the 1st of July 2006.

[2] cf. *Knieps* (2005).

[3] cf. *Müller/Vogelsang* (1979); *Finsinger/Kraft* (1984) and for the rate of return regulation, which has analogous incentive effects, *Averch/Johnson* (1962); *Takayama* (1969); *Baumol/Klevorick* (1970); *Bailey* (1973); *El-Hodiri/Takayama* (1970); *Peles/Stein* (1976); *Das* (1980); *El-Hodiri/Takayama* (1981); *Train* (1991); *Bös* (1994).

[4] For an overview cf. *Joskow/Schmalensee* (1986).

[5] cf. *Littlechild* (1983); *Bradley/Price* (1988); *Acton/Vogelsang* (1989); *Cabral/Riordan* (1989); *Train* (1991).

[6] see Jamasb/Nillesen/Pollitt (2004), p. 827.

[7] cf. *Berg et al.* (2006).

visaged in the medium-term in Germany. This regulation scheme proposed by Shleifer (1985) employs an average method to determine the benchmark. According to this method the results of the benchmarking will be translated into targets for the X-factor.

The German Regulator stated in his “Report on the introduction of an incentive regulation” from 30th June 2006 that he prefers to abstain from a pure yardstick regulation in the short run.[8] Rather he intends to adapt a revenue-cap-regulation for the first two periods (6-8 years). Here a benchmarking consists of two elements. On the one hand, there is a general productivity gain target (X_{gen}) while on the other hand there is an individual efficiency gain target (X_{ind}). The latter shall facilitate the introduction of an undiluted yardstick regulation by harmonising costs of firms. Individual “glide paths” shall alleviate the full force of the efficiency targets and permit a slow rapprochement to the required efficiency level. The individual “glide paths” will most likely be used as long as the revenue-cap-regulation, i.e., during the first two regulatory periods. The report further highlights the sustainability-problem of the benchmark and thus proposes an according modification of the benchmarking.[9]

After a short overview of the benchmarking-methods and its well-known problems we will investigate the possibility of deriving grid charges from a benchmark which allow for a sustainable network operation. Sustainability of network operation implicates that an efficient network operator is able to refinance his required investments entirely through transmission charges.

Firstly, we will examine this by use of a simple model which does not consider a different age structure of the capital stock, i.e., assets of different network operators. In this model the sustainable refinancing of investments seems possible. Considering a heterogeneous age structure of the capital stock the result changes dramatically – provided that the unrealistic assumption of exogenously given and constant lifetime of the assets is abandoned.

2 Methods and problems of benchmarking

There is a multitude of benchmarking methods at the disposal of the regulator.[10] For a comprehensive overview of the different methods we refer to a study prepared by Berg et al. (2006). Jamasb/Pollitt (2001) provide an excellent overview of by then completed studies. One can basically divide the different benchmarking techniques into parametric and non-parametric methods. The parametric methods are based on regression analyses and thus imply specific assumptions regarding the underlying production function. All production functions are assumed to be identical for all network operators for example. As a consequence, a lot of specific influences have to be neglected. Non-parametric methods on the other hand allow for a greater variety. Based on linear programming techniques they make it possible to choose different combinations of factors of production in different firms. Since more similar firms are

---

[8] see BNetzA (2006), p.14

[9] see BNetzA (2006), p.53ss.

compared, only “locally” efficient network operators will be determined. The non-parametric benchmarking will therefore allow a higher number of firms to be considered efficient.[11]

Further, benchmarking methods can be divided into “frontier” and “non-frontier”-methods. “Frontier”-methods determine the efficient frontier of firms which set the benchmark in a comparison of firms.[12]

These methods can lead to significantly differing results.[13] Consequently the result of the benchmarking partly depends on the somehow arbitrary decision of the regulator to chose a method: firstly, whether to use one or several methods and secondly, if he decided for the latter, how to combine them effectively.

Additionally, network operators on the frontier have the potential to behave strategically. Jamasb/Nillesen/Pollitt (2004) identify cost manipulation (accounting rules, definitions, rate on capital employed), regulatory capture in the context of the regulator’s choice of methods (benchmarking models, variable selection and their weighting, retention of information) and fusions to be the most important options of network operators to behave strategically.

“Non-frontier“-methods compare average values so to reduce the possible channels of influence of network operators to set the benchmark and to behave strategically. When the regulator neglects the eventual occurrence of strategic behaviour he risks deterred benchmarking results which would lead him to set suboptimal incentives to the regulated firms.

Another source of potential problems is the choice of the most suitable variables. Shuttleworth (2005) describes a fundamental problem in conjunction with searching for the most suitable variables and their definitions in a benchmarking process: The resulting inefficiency from a benchmarking comparison of a grid operator is not necessarily caused by the grid operator actually being inefficient. The undefined residuals could also result from a misspecification of the benchmarking model. Therefore Shuttleworth challenges the accuracy of benchmarking studies in general. He claims that benchmarking should more be regarded as an instrument for the identification of relevant cost drivers.

Filippini/Wild (2002) show in a both qualitative and quantitative study that benchmarking bears the potential to discriminate on the basis of regional differences between network operators. If cost driving structural differences result from a different public service obligation, they

---

[10] For efficiency measurement in general cf. *Farrel* (1957), *Fried/Lovell/Schmidt* (1993), *Färe/Grosskopf/Lovell* (1985, 1994).

[11] cf. *Burns/Jenkins/Riechmann* (2005).

[12] The most commen methods are simple average cost, Total Factor Productivity and Ordinary-Least-Squares amongst the average methods and Corrected Ordinary Least Squares, Stochastic Frontier Analysis (/Stochastic Frontier Estimation) and Data Envelopment Analysis amongst the frontier methods. For DEA cf. *Charnes/Cooper/Rhodes* (1978), *Banker/Charnes/Cooper* (1984), *Coelli/Rao/Battese* (1998); for SFA cf. also *Coelli/Rao/Battese* (1998).

[13] cf. e.g. *Burns/Jenkins/Riechmann* (2005), *Cunningham/de Joode* (2005), *Shuttleworth* (2005). A comparison of two methods highlighted in the German discussion, DEA and SFA (/SFE) is done by *Ajodhia/Petrov/Scarsi* (2003).

cannot be influenced by the network operator and have therefore to be included in the regulatory benchmarking. This basic requirement already defines numerous postulates for the benchmarking. Neither customer structure (such as density, urban sprawl or dispersion) and topography/geography nor climatic impact must be neglected. Regional differences in prices of production factors also influence the supply cost; differences in wages between urban and rural areas or Eastern and Western Germany can be significant in this sense. It should also be differentiated between the existing voltage levels of transmission lines, such as high or low-voltage power line. Since they differ in components used, power transmitted and other characteristics, they have different average costs. In addition to these external influences, the non-consideration of other significant individual influences could lead to unjustified discrimination. Both architectural expenditures for devices in areas of tourism and costly historic pavement restorations are examples for these individual influences.[14] Similarly the demographic development can not be directly influenced by the grid operator. The ongoing migration into cities and the resulting declining population in numerous supply areas make the affected network operators look a lot more inefficient than the unaffected ones. This holds true at least in a transition period as long as expenditures for in the meanwhile oversized network structures can be asserted as costs.[15]

In contrast to the above mentioned factors that cannot be influenced by the grid operator there are also factors that can be directly influenced by the network operator’s actions. Amongst them we find the size of the network operator (on a cost or revenue basis) or the delivered services (peak demand and number of customers).[16] Since transmission and distribution network infrastructure is subject to economies of scale effects, it has to be decided whether or not to consider them in the benchmarking process.[17] From an economic point of view, a method of constant returns to scale seems to give the best incentives for the network operators to choose their long-run efficient scale. But taking into account political considerations, the answer is more ambiguous: Small network operators are exposed to a high cost pressure in the short run by this proceeding and consequently get discriminated.[18]

The provided quality level also belongs to the group of factors that can be influenced. The quality level is, however, a result of historical developments and can only be influenced in the medium term, due to the slackness of the cost-quality-relationship. Different initial quality levels should therefore be accepted by a regulator and – at least during a transition phase – be accounted for in the cost base determination. It should furthermore be noted that it is not only the costs which is relevant but also the customers who are affected by external utility effects

---

[14] cf. also *Müller-Kirchenbauer/Kremp/Ritzau/Evers* (2002); *Fritz/Lüdorf/Haubrich* (2002); *Fritz/Zimmer* (2004) and *Büchner/Nick* (2004).

[15] cf. *Montebaur/vom Felde* (2006).

[16] cf. also *Haubrich/Zimmer/Fritz/Mollemeier* (2002).

[17] Regarding cost studies cf. *Filippini* (1996, 1997, 1998) and *Filippini/Wild* (1998) for Switzerland or *Salvanes/Tjotta* (1994, 1998) for Norway; *Giles/Wyatt* (1993) for New Zealand and *Yatchew* (2000) for Canada.

[18] cf. *Filippini/Wild* (2002).

through the chosen quality level. This external effect can vary depending on the customer structure, for instance, and thus justifies differing cost levels to the same degree that they reflect the different valuation or, more exactly, the willingness to pay of the respective customer group.[19]

Furthermore, especially for non-parametric methods like the Data Envelopment Analysis there is a substantial sensitivity to data errors. Single network operators can unjustifiably appear to be extremely efficient in this way and cause excessive efficiency targets for all other firms.[20]

Still another problem is that the resulting price and revenue targets do not solely depend on the employed method and its results. The translation of these results into productivity targets also offers an additional wide scope of suboptimal incentive setting for the firms. In this context the attention has to be concentrated on the distribution of the allowed profits or revenues over the efficiency spectrum and the length of the adjustment path or glide path that determines the period over which a network operator has to achieve his respective efficient state. Shuttleworth (2005) remarks, that objective analysis does not exist that could help determining the efficient length of the glide path. As a consequence the regulator’s decision remains somewhat arbitrary in this respect.

Additionally, the considered cost base for the benchmarking is of vital importance for the impact of incentives on the firms. There are mainly two different alternatives being discussed at the moment: a benchmarking on a total expenditure basis (TOTEX) which includes capital expenditure (CAPEX) as well as operating expenses (OPEX) on the one hand and a benchmarking that relies on operating expenses exclusively, on the other. The former approach is used both in the Netherlands and Norway while the latter is used in England. In the case of a solely OPEX benchmarking the CAPEX will be treated separately in a different approval procedure. This so-called “building block approach” determines the CAPEX separately and adds a sliding scale incentive mechanism with a regulatorily defined return on capital employed. As for Germany, the regulator envisages a TOTEX benchmarking.

The TOTEX benchmarking has the advantage of companies taking both CAPEX and OPEX into account during their minimization process. They then, ideally, tend to a global cost minimum.

The inclusion of CAPEX into the benchmarking also bears, however, a serious danger for a companies’ capability of refinancing its assets. Ajodhia/Kristiansen/Petrov/Scarsi (2005) have shown in some basic calculations that different points in time of investment and different amortization periods can cause distortions in a cost benchmarking process. They do not, however, consider depreciation on already existing capital stock in their calculation.

Above all and from an economic point of view it has to be remarked that the considered costs in the benchmarking process are nothing but average costs including overheads (cost per line

---

[19] For problems in the context of the consideration of quality in benchmarking cf. *Ajodhia* (2006).

[20] cf. basically for potential problems and the treatment of data problems *Berg et al.* (2006).

length or the like). This is important when talking about efficiency because in the context of common economic pricing concepts we will find the average cost concept amongst the least efficient ways to determine the price of upstream goods.[21] A network operator has a wide range of opportunities to strategically allocate overheads. Normally he will chose an allocation key like quantities or the like and not optimize social welfare considering elasticities and cross-price elasticities as Ramsey-Pricing does respectively for different customer groups and products, for example.[22] With a profit maximizing company the result will be far from efficient. In the context of upstream goods Hausman/Tardiff (1995) proposed to set prices equal to incremental costs with an additional lump sum tax. But their optimality – i.e. equality to Ramsey prices – holds solely in the absence of incentive distortions by the regulator and economies of scale and density.[23] This is normally not the case for electricity networks. Vogelsang (2003) provides further arguments against markups on incremental costs.[24] Double marginalization, for instance, would involve that overheads should be passed through to the last step of the value chain. However, there are a few arguments against marginal cost pricing being mostly related to the lump-sum tax: It is neither clear if the social value of the service will outweigh its social cost nor if the lump-sum tax will lead to the socially optimal distribution.[25] Setting sufficient incentives to reduce costs for the lump-sum part can also arise to a significant problem. The application of markups thus seems inevitable but the arbitrarily chosen markups by the network operators have to be classified definitely as inefficient.

Hence developing efficient pricing schemes for network operators is not an easy task and defining a benchmarking approach which addresses the efficiency of the pricing would be even more ambitious. We therefore stick to the conventional approach of benchmarking based on per unit cost.

In the following we will show how the vintage structure of the capital stock will influence depreciation, benchmarks and the capability of refinancing. We first set up a simple model without any explicit age structure as a reference case. The capability of refinancing the capital stock is possible in this context if the amortization periods are identical and appropriate. In a second step we analyse the consequences of a heterogeneous capital structure by adding ‘capital vintages’ to the model still assuming a constant lifetime of the capital goods (‘sudden death’). Also in this case we show that benchmarking is feasible without discrimination or difficulties concerning long-term sustainability of grid investment.

Finally we consider a heterogeneous capital stock with non-constant lifetime. Non-constant lifetime may either result from stochastic decay (failures) or from endogenous replacement decisions or a combination of both. Whatever being the cause, we show that under these con-

---

[21] For general information about upstream good pricing in the context of the telecom sector cf. *Vogelsang* (2003).

[22] For Fully Distributed Cost Pricing cf. ANDERSEN BUSINESS CONSULTING (2002).

[23] cf. *Hausman/Tardiff* (1995).

[24] cf. *Vogelsang* (2003), *Viscusi et al.* (2000).

[25] cf. *Borrmann/Finsinger* (1999).

ditions a pure benchmarking approach among firms with heterogeneous capital vintage structure will result in setting a benchmark, which will not allow for a sustainable refinancing of the capital used.

3 Simple Model: Homogeneous capital stock

Starting point of our considerations is a set S of firms i, which underlie an incentive regulation regarding their grid charges. The permitted revenue is determined through regulatory benchmarking, which further implies a pure yardstick regulation. We take the following assumptions as starting point to keep the argumentation as simple as possible:

- *The firms do not differ regarding their network structure.* Therefore the benchmarking can be conducted by a simple cost comparison. More complicated approaches like DEA or SFA will not be necessary to determine the efficient cost base for the respective network operator.
- *Firms do only offer a unique network service each. Their quantity remains constant.* Therefore price- and revenue-cap regulation are identical.
- *The provision of the network service requires only capital goods of the same type.* As a consequence different lifetimes and amortization periods do not have to be taken into account for different assets.
- *There is no technological progress over time.* Thus the capital stock K, which is necessary for the efficient provision of the service, does not change over time.

  $$K_t - K_{t-1} = 0 \quad \forall t \tag{1}$$
- *Operating expenses are negligible.* This means that there are solely capital expenses which have to be taken into account for service provision.
- *Inflation rate is zero.* A calculation with constant instead of nominal values could be conducted as well. For reasons of clarity we renounce modeling inflation in the following discussion.[26]
- *The relevant discount rate is zero.* This surely is a quite unconventional assumption. On the other hand it simplifies the following discussion substantially because the present value of cash flow series can be written as a simple sum without having to employ discounting. Furthermore the CAPEX relevant for the benchmarking reduces to the plain depreciation cost, whereas usually also payments have to be considered**.**

---

[26] In conjunction with the assumption of the absence of technological progress it follows that there is no difference between the cost accounting principles of *Realkapitalerhaltung* (“real capital sustainment”) and *Nettosubstanzerhaltung* (“tangible asset sustainment”) distinguished in the German regulatory debate. cf. *Sieben/Maltry* (2002).

- *All network operators work efficiently.* I.e. that a state being achieved after several regulatory periods is observed, when regulation will have already been successful.

All assumptions are chosen to simplify the analytical treatment of the problem under study. However, the basic question to be answered remains the same: Is the advised regulatory regime sustainable, i.e. does it allow the firms to recover their costs from their permitted revenues permanently? The answer to this basic question is probably not substantially modified, if we replaced the restrictive assumptions by more general ones.

In a first simple model additionally to the previous hypothesis we further assume that the capital stock is not only a homogeneous asset but that it is neither differentiable with respect to its age structure. With an average lifetime of the asset of N years we have annual investment needs I_t

$$I_t = \delta K_t \tag{2}$$

using the definition of an annual failure rate δ:

$$\delta = \frac{1}{N} \tag{3}$$

The relevant cost base for regulation C_t results from:

$$C_t = aK_t \tag{4}$$

We assume a linear depreciation with the deprection rate a as the reciprocal value of the amortization period A:

$$a = \frac{1}{A} \tag{5}$$

Both K_t and C_t are identical for all firms because firms are homogeneous regarding their network structure and efficiency. That is why the indexing of the values over the firms i was suppressed so far.

The benchmark B_t for regulation is derived from:

$$B_t = \min_{i \in S} C_{t,i} \tag{6}$$

In view of the preceding we get:

$$B_t = C_{t,i} \qquad \forall i \in S \tag{7}$$

A necessary condition for a sustainable grid operation is however:

$$B_t = I_t \tag{8}$$

i.e. the annually necessary investments have to be covered exactly by the revenues determined by the benchmark B_t.

This is the case if the depreciation period is set equal to the average lifetime

$$A = N \tag{9}$$

or equivalently:

$$a = \delta \tag{10}$$

This result is simple, even close to trivial and corresponds to the practical regulatory rule that the depreciation period used rate should correspond to the technical lifetime.

In the following we will show that this rule will lead to sustainability problems when the heterogeneous age structure of the capital stock is considered, if the firms are heterogeneous with respect to this age structure and if asset lifetimes are variable.

4 Extended Model: heterogeneous capital stock

In reality the capital stock of firms is not homogeneous. It rather consists of different assets with different acquisition- or installation dates, corresponding to different vintages. The total capital stock $K_{G,t,i}$ of a firm i at time t is therefore the sum of the respective capital fractions $K_{t,i,\tau}$ with their respective age τ and corresponding installation date $t - \tau$

$$K_{G,t,i} = \sum_{\tau=1}^{N_{\max}} K_{t,i,\tau} \tag{11}$$

Thereby the vintages within the amortization period underlie depreciation. Under linear depreciation a depreciation rate of $a = 1/A$ has to be taken. Consequently the corresponding cost base of period t is:

$$C_{t,i} = \sum_{\tau=1}^{A} aK_{t,i,\tau} \tag{12}$$

The replacement need and thus the investment are in this setting generally:

$$I_{t,i} = \sum_{\tau=1}^{N_{\max}} \delta_\tau K_{t-\tau+1,i,1} \tag{13}$$

With δ_τ describing the replacement rate for the assets of age τ, i.e. the fraction of the initial capital stock $K_{t-\tau+1,i,1}$, that has to be replaced after τ years. The following dynamic equations hold for the evolution of capital vintages over time:

$$\begin{aligned} K_{t,i,1} &= I_{t-1,i} \\ K_{t,i,\tau} &= K_{t-1,i,\tau-1} - \delta_\tau K_{t-\tau+1,i,1} \\ &= K_{t-\tau+1,i,1}\left(1 - \sum_{\tau'=1}^{\tau} \delta_{\tau'}\right) \qquad \forall \tau > 1 \end{aligned} \tag{14}$$

Investments undertaken in year *t-1* will hence only be added to the capital stock in the successive year t. Reference for the replacement rate δ_τ of age τ is always the respective initial capital stock $K_{t-\tau+1,i,1}$ with age 1 (which corresponds the investment $I_{t-\tau}$ of year $t-\tau$)

For the δ_τ, the following identity has to be satisfied:

$$\sum_{\tau=1}^{N_{\max}} \delta_\tau = 1 \tag{15}$$

Moreover, all δ_τ have to be nonnegative of course. Whether the δ_τ result from an exogenous aging or failure process or from an optimizing calculus of the asset owners, is not of primordial importance for the subsequent considerations.

Some possible distributions for δ_τ are illustrated in picture 1. Obviously in all but the most simple cases the mean lifetime differs from the maximum lifetime. The only exception is the case of a constant and deterministic lifetime (depicted on the upper left hand side). In the following we will initially discuss this simple case and subsequently pass over to cases of variable lifetime.

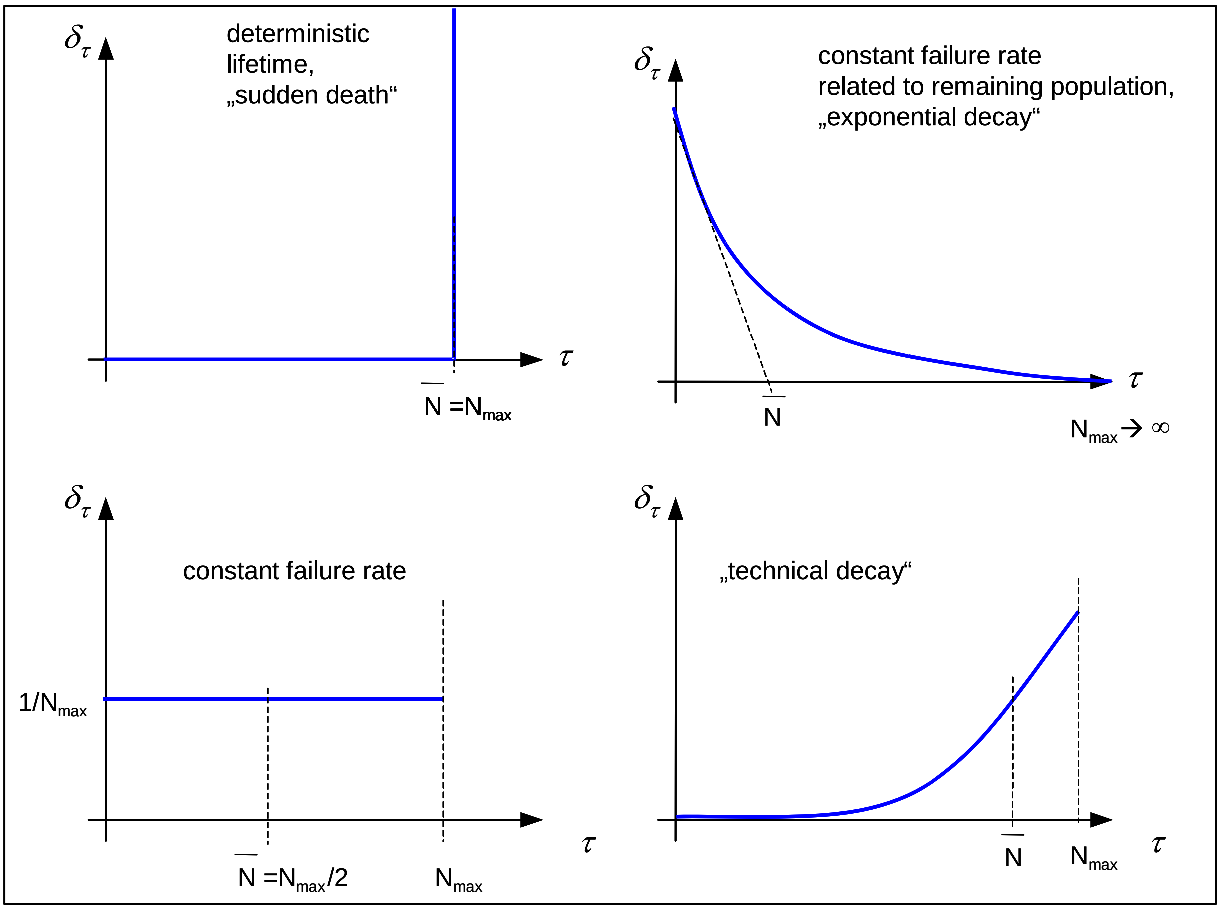

figure 1: Different replacement rates.

4.1 Fixed lifetime of capital vintages

To refinance the initial investments over the lifetime of a vintage, the sum of the allowed revenues has to be equal to the initial investment volume – keeping in mind the assumptions of zero inflation and discount rate. The permitted revenue in a year of observation t result from the benchmark:

$$B_t = \min_i C_{t,i} \tag{16}$$

If the amortization period A is set equal to the lifetime N_{max} assumed as fixed like in the simple model, equation (12) will result in:

$$C_{t,i} = a\sum_{\tau=1}^{N_{\max}} K_{t,i,\tau} = aK_{G,t,i} \tag{17}$$

Given that network operators are structurally identical and there are no differences regarding their efficiency and since furthermore the necessary capital stock does not change without technological progress, capital stocks are identical between grid operators and over time:

$$K_{G,t,i} = K_G \qquad \forall t, \forall i \tag{18}$$

For the benchmark and thus for the permitted revenues, one obtains from the above equations:

$$B_t = aK_G = C_{t,i} \qquad \forall t \tag{19}$$

The assumption that capital goods have a fixed lifetime leads to the following distribution for δ_τ:

$$\delta_\tau = \begin{cases} 0 & if \quad \tau < N_{\max} \\ 1 & if \quad \tau = N_{\max} \end{cases} \tag{20}$$

From equation (13) it can be derived for the investment needs:

$$\begin{aligned} I_{t,i} &= K_{t-N_{\max}+1,i,1} \\ &= I_{t-N_{\max},i} \end{aligned} \tag{21}$$

i.e. the result are fixed investment cycles of length $N_{\max}$.

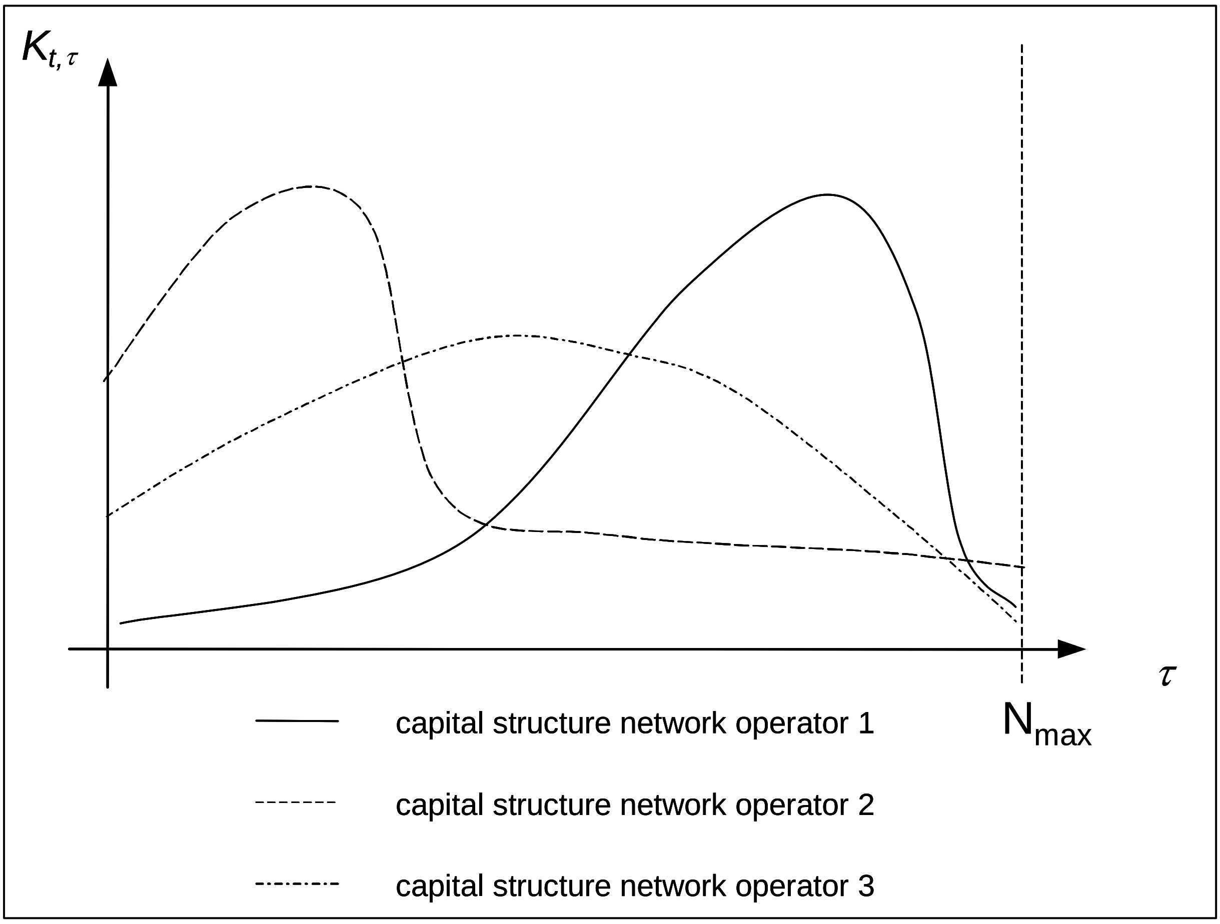

figure 2: companies with different capital structures

If the initial capital stocks for the different firms vary (see figure 2) the annual investments also will. But this will not have any effect on the benchmark because the benchmark is based on depreciations which comprise the entire capital stock as long as lifetime and amortization period are identical.

For a single year *t* and a particular firm *i* it can thus well occur that:

$$I_{t,i} \neq B_t \tag{22}$$

Particularly in the case of a firm disposing of assets which have an above average age, for some years $I_{t,i} > B_t$. Hence investments can not be covered by permitted revenues in that particular year. But the key question whether or not firms incur (systematic) deficits under the regulatory regime for the sustainability of regulation is deciding.

To determine profits or losses a look at the firm's balance sheet is helpful. The incurred losses or profits can be directly derived. For the modelled network operator the following transactions are relevant for the firm's balance sheet:

- Addition of tangible assets corresponding to the amount of investments $I_{t,i}$.
- Reduction of financial assets $Z_{t,i}$ and/or increase of liabilities $V_{t,i}$ for financing investments
- Cash inflow, i.e. addition of liquid assets from transmission and distribution charges. Those are determined by the benchmark and thus are equal to B_t.
- Diminuition of the asset base corresponding the amount of depreciation. Given the above assumptions these are equal to costs $C_{t,i}$.

With exception of the financing of investments by credits all of the above activities concern the asset side of the balance sheet. As the form of financing has no systematic impact on efficiency (in this simple model), for the sake of simplicity the financing of investments is assumed to be undertaken from liquid assets. For this reason only changes on the asset side have be considered. The firm will realise profits $G_{t,i}$ if additions on the asset side will exceed asset reductions. In contrast it will realise losses if reductions on the asset side will exceed additions, formaly:

$$G_{t,i} = I_{t,i} - Z_{t,i} + B_t - C_{t,i} \tag{23}$$

If bargaining of extra discounts or in-house production of assets are excluded the amount of financial assets $Z_{t,i}$ necessary for the financing of investments will be equal to the amount of investments $I_{t,i}$. Accordingly the profit balance reduces to:

$$G_{t,i} = B_t - C_{t,i} \tag{24}$$

Benchmarking will lead to sustainable network operation if benchmarking revenues do not fall short of expenses systematically. In our case expenses solely based on depreciation. But from equation (19) it results directly that for all firms and all years:

$$G_{t,i} = 0 \qquad \forall t,\ \forall i \tag{25}$$

This result is derived under the assumption that the amortization period is equal to the lifetime. In the subsequent section we will show that the generalisation of this approach for the case of variable lifetimes is problematic.

4.2 Variable lifetime of capital vintages

In practice it is not probable that all production facilities of the same type also have the same lifetime. On the one hand premature failure can be observed. Such failures are rather stochastic, partly depending on variations in the asset production process (e.g. material inhomogeneities), partly depending on stochastic differences in the material wear and tear during operation (e.g. varying weather impact on lines). Alongside these stochastic premature failures an optimised replacement strategy can lead to the choice of varying lifetimes for different production facilities of the same type as a consequence of unequal stress. Qualitatively in most cases a progression as depicted in figure 1 on the bottom right will result. It shows the case of low replacement rates during the first years and higher ones later around the "customary lifetime".
Independently of the precise distribution of failures and corresponding replacement rates it has to be noted that in all cases lifetime is a variable parameter and that the mean lifetime $\overline{N}$ is exceeded or undercut for particular production facilities. In reality it will be often even difficult to determine the exact upper limit $N_{\max}$ for the lifetime, especially for newly developed production facilities. This occurs notably in the case of a constant failure rate for the remaining population as examplified on the upper right hand side of figure 1.
In this context the benchmark and consequently the capability of refinancing investments is again highly influenced by the depreciation period A. Three alternatives are imaginable in principle:

- $A = \overline{N}$: *the depreciation period is set equal to the average lifetime.* Given the optimality conditions derived in the above sections this seems a natural choice.
- $A < \overline{N}$: *the depreciation period falls short of the average lifetime.* This allows to avoid the situation of having to replace production facilities before the ending of the depreciation period. Such premature replacements always have to be accompanied by an extra depreciation on the replaced asset in the balance sheet. Otherwise no longer usable assets would still be valued in the balance sheet.
- $A > \overline{N}$: *the depreciation period exceeds the average lifetime, at the extreme case it is* $A = N_{max}$. This avoids the use of already amortized production facilities, which would otherwise distort the benchmark (see below).

The general equations (23) and (24) still hold for the profit in all cases. But then for the amortization and consequently the expenses of the firm equation (12) has be extended:

$$C_{t,i} = \sum_{\tau=1}^{A} \left(aK_{t,i,\tau} + \delta_\tau (1-\tau a) K_{t-\tau+1,i,1} \right) \tag{26}$$

Here the second term $\delta_\tau (1-\tau a) K_{t-\tau+1,i,1}$ reflects the extra depreciation on assets with residual value $(1-\tau a) K_{t-\tau+1,i,1}$ having to be replaced during the depreciation period.[27] Defining the replacement rate $\tilde{\delta}_\tau$ with respect to the residual capital stock

$$\tilde{\delta}_\tau = \frac{\delta_\tau}{1-\sum_{\tau'=1}^{\tau-1} \delta_{\tau'}} \tag{27}$$

so $\tilde{\delta}_\tau \leq 1$ throughout, equation (26) can be written:

$$C_{t,i} = \sum_{\tau=1}^{A} \left(a + \tilde{\delta}_\tau (1-\tau a) \right) K_{t,i,\tau} \tag{28}$$

Or equivalently:

$$\begin{aligned} C_{t,i} &= a \sum_{\tau=1}^{N_{\max}} K_{t,i,\tau} - a \sum_{\tau=A+1}^{N_{\max}} K_{t,i,\tau} + \sum_{\tau=1}^{A} \tilde{\delta}_\tau (1-\tau a) K_{t,i,\tau} \\ &= aK_G - a \sum_{\tau=A+1}^{N_{\max}} K_{t,i,\tau} + \sum_{\tau=1}^{A} \tilde{\delta}_\tau (1-\tau a) K_{t,i,\tau} \end{aligned} \tag{29}$$

i.e. total costs consist of regular depreciation on the total capital stock diminished by depreciation on capital fractions with age greater than the depreciation period and increased by extra depreciation accounting for premature failure. While the first term is independent of the capital structure this does not hold for summands two and three. The second (negative) term takes high values particularly for firms with relatively old assets. Whereas the third term will only show high values if production facilities are replaced before the regular ending of the depreciation period.

Whatever the choice of the depreciation period, be it longer, shorter or equal compared to the average lifetime, one of the latter two terms will always be different from zero. If the amortization period is chosen to be relatively short (i.e. $A < \overline{N}$) premature depreciation can be avoided almost completely and the latter term can be eliminated. Yet conversely the fraction of capital being captured by the second term will grow because the distance between depreciation period A and maximum lifetime $N_{\max}$ is relatively large. If the opposite extreme of an amortization period equal to the maximum lifetime is chosen ($A=N_{\max}$) the second term will disappear. But in this case a lot of premature depreciation will occur with the consequence of the third term being of considerable relevance. Hence the individual capital structure always

---

[27] For the weighting factors of the above equation it can be proven that:

$$\sum_{\tau=1}^{A} \left(a \left(1 - \sum_{\tau'=1}^{\tau-1} \delta_{\tau'} \right) + \delta_\tau (1-\tau a) \right) = 1$$

i.e. that each vintage is depreciated exactly once altogether under the consideration of regular and extra depreciation.

has an influence on effective costs even under the assumption of structurally comparable firms which additionally are of identical efficiency. Obviously this result holds also for any value for A lying between the extreme points considered.

The basic benchmarking relationship (16) then still holds, but in this case from the principle relation

$$B_t \leq C_{t,i} \tag{30}$$

it follows that the set S of all firms (with different vintage structures) is partitionable into two disjunct, non-empty sets:

$$\begin{aligned} S_{B,t} &= \{ i \in S \mid B_t = C_{t,i} \} \\ S_{NB,t} &= \{ i \in S \mid B_t < C_{t,i} \} \end{aligned} \tag{31}$$

The firms belonging to $S_{NB,t}$ show a deficit for year t according to equation (24). This deficit can not be refinanced by profits in the preceding or following years because from the benchmarking relation (30) it results that at most a firm could achieve a zero deficit. Thus the benchmarking cannot lead to sustainable network operation if the age structure of assets for firms is different in the first place.

5 Conclusion

We have investigated by the means of a theoretical model to what extent sustainable investment of network operators under pure benchmarking is possible. The heterogeneity of assets of particular network operators has been identified as a main problem of TOTEX benchmarking. Network operators with relatively old assets will set the benchmark since they partly produce ‘without costs’. The resulting benchmarks will therefore determine unrealistic efficiency targets for the firms and thus will lead to the incapability of refinancing the long-term necessary investments. Against the background of rather increasing investment needs (due to wind power or old facilities) the question has to be posed, how investments can be assured anyway and how unfair discrimination of benchmarked firms can be avoided.

A standardisation of depreciation and booking rules is only partly helpful because this alleviates comparability problems of particular network operators and distortions in the benchmarking process are alleviated. But the above described problem of systemically insufficiently high benchmarks as a consequence of heterogeneous capital structures is not solved.

The German Regulator (Bundesnetzagentur) has identified the problem partly at least being urged by the network operators and has thus proposed not to allow only for book depreciation costs in their benchmarking.[28] Rather it is proposed to consider the usage of assets after their total depreciation by the means of an “annualized cost accounting”. However the regulator does not provide any information to what extent this annualized cost accounting will be ap-

---

[28] cf. BNetzA (2006), p. 53 – 55.

propriate to provide consistent results in the context of the above sketched environment of on the one hand variable and on the other hand at least partially influenceable lifetime of capital goods.

Also imaginable could be a system of inevestment budgets similar to the English one instead of the CAPEX benchmarking.[29] Here OPEX and CAPEX are regulated separatly. The benchmarking includes solely OPEX (partial benchmarking) whereas CAPEX are to be estimated and approved separately. Thereby CAPEX underlie a sliding scale incentive regulation.

Main disadvantage of this approach is the regulator's duty to define the optimal OPEX-CAPEX ratio. Otherwise one-sided cost optimisation towards the best possible position in the benchmarking is to be expected and would further lead to a tendency towards overcapitalisation. But then it still exists the danger of a 'double jeopardy', where unrealistic benchmarks are set caused by one-sided optimisations of either CAPEX or OPEX.

For the application in Germany it is important to remark that different amortization and accounting rules complicate any comparison – even in pure OPEX benchmarking. Furthermore the large number of network operators makes it difficult to conduct individual checks of capital cost applications and requires standardised procedures.

Overall it has to be noted that there is a basic trade off between creating highest possible incentives for an efficient network operation under simultaneous renouncement to micro management on the one hand and the requirement not to risk the necessary investments for sustainable network operation. However, the appropriate treatment of capital costs plays a decisive role. Further research should above all investigate the multiple interdependencies between endogenous replacement decisions and the cost base applied for the benchmarking.

---

[29] cf. OFGEM (2004a) and OFGEM (2004b).

References

Acton, J.P., I. Vogelsang (1989), Introduction (to Symposium on Price Cap Regulation). Rand Journal of Economics, Vol. 20, pp. 369-372.

Ajodhia, V.S. (2006), Regulating beyond Price, Integrated Price-Quality Regulation for Electricity Distribution Networks. PhD Thesis, Delft University of Technology, Delft.

Ajodhia, V., K. Petrov and G.C. Scarsi (2003), Benchmarking and its Applications. Zeitschrift für Energiewirtschaft, Vol. 27, pp. 261-274.

Ajodhia, V., K. Kristiansen, K. Petrov, G.C. Scarsi (2005), Total cost efficiency analysis for regulatory Purposes: statement of the problem and two European case studies. Tagungsbeitrag zur WIP-"4th Conference on Applied Infrastructure Research", Berlin, 8. Oktober 2005, proceedings, URL: http://wip.tu-berlin.de/workshop/2005/papers/petrov_scarsi_kristiansen_adjohia_Total_Costefficiency_analysis_for_regulatry_purposes.pdf, last access 7th of July 2006.

ANDERSEN BUSINESS CONSULTING (2002): Study on the implementation of cost accounting methodologies and accounting separation by telecommunication operators with significant market power. In http//:www.europa_eu.int/information_society / topics / telecoms /implementation/costaccounting 2002 (last access 3rd of June 2004).

Averch, H., L.L. Johnson (1962), Behavior of the Firm under Regulatory Constraint. American Economic Review, Vol. 52, pp. 1052-1069.

Bailey, E.E. (1973), Economic Theory of Regulatory Constraint. Lexington, Mass.

Banker, R.D., A. Charnes, W.W. Cooper (1984), Models for Estimation of Technical and Scale Inefficiencies in Data Envelopment Analysis. Management Science, Vol. 30, pp. 1078-1092.

Baumol, W.J., A.K. Klevorick (1970), Input Choices and Rate-of-Return-Regulation: An Overview of the Discussion. Bell Journal of Economics and Management Science, Vol. 1, pp. 162-190.

Berg, S. et al. (2006), Survey of Benchmarking Methodologies. Studie im Auftrag der Weltbank. URL: http://www.purc.org/documents/Benchmarking_Survey_Report.pdf. last access 7th of July 2006.

Borrmann, J., J. Finsinger (1999): Markt und Regulierung. Verlag Franz Vahlen GmbH, München

Bös, D. (1994), Pricing and Price Regulation. 3. A., Amsterdam, Ch. 26 und Ch. 28.

Bradley, I., C. Price (1988), The Economic Regulation of Private Industries by Price Constraints. Journal of Industrial Economics, Vol. 37, pp. 99-106.

Büchner, J., W. Nick (12/2004), Strukturklassen zum sachgerechten Vergleich von Verteilnetzbetreibern. Energiewirtschaftliche Tagesfragen, Vol. 12, pp. 816-820.

Bundesnetzagentur (BNetzA) (2006), Bericht der Bundesnetzagentur nach § 112a EnWG zur Einführung der Anreizregulierung nach § 21a EnWG. Published 30th of June 2006.

Burns, P., C. Jenkins, C. Riechmann (2005), The Role of Benchmarking for Yardstick Competition. Utilities Policy, Vol. 13, pp. 302-309.

Cabral, L.M.B., M.H. Riordan (1989), Incentives for Cost Reduction under Price Cap Regulation. Journal of Regulatory Economics, Vol. 1, pp. 93-102.

Charnes, A., W.W. Cooper, E. Rhodes (1978), Measuring the Efficiency of Decision-Making Units. European Journal of Operational Research, Vol. 2, pp. 429-444.

Coelli, T., D. S. P. Rao, G. E. Battese (1998), An Introduction to Efficiency and Productivity Analysis. Kluwer, Boston.

Cunningham, S.W., J. de Joode (2006), Firm Behaviour under Incentive Regulation: The Inefficiencies of Benchmarking. "29th IAEE International Conference", Securing Energy in Insecure Times Proceedings, Potsdam, 7th to 10th of June 2006.

Das, S. (1980), On the Effect of Rate of Return Regulation under Uncertainty. American Economic Review, Vol. 70, pp. 456-460.

El-Hodiri, M., A. Takayama (1973), Behavior of the Firm under Regulatory Constraint: Clarifications. American Economic Review, Vol. 63, pp. 235-237.

El-Hodiri, M., A. Takayama (1981), Dynamic Behavior of the Firm with Adjustment Costs under Regulatory Constraint. Journal of Economic Dynamics and Control, Vol. 3, pp. 29-41.

Energiewirtschaftsgesetz (EnWG) (2005), Zweites Gesetz zur Neuregelung des Energiewirtschaftsrechts. Vom 13. Juli 2005 (BGB l. part I, p.1953, 12th of July 2005).

Färe, R., S. Grosskopf, C.A.K. Lovell (1985), The Measurement of the Efficiency of Production. Kluwer, Boston.

Färe, R., S. Grosskopf, C.A.K. Lovell (1994), Production Frontiers. Cambridge University Press, Cambridge.

Farrel, M.J. (1957), The Measurement of Productive Efficiency. Journal of the Royal Statistical Society, Series A, Vol. 120, pp. 253-281.

Filippini, M. (1996), Economies of scale and utilization in the Swiss electric power distribution industry. Applied Economics, Vol. 28, pp. 543-550.

Filippini, M. (1997), Elements of the Swiss Market for Electricity. Physica-Verlag, Berlin.

Filippini, M. (1998), Are municipal electricity distribution utilities natural monopolies? Annals of Public and Cooperative Economics, Vol. 2, pp. 157-174.

Filippini, M., J. Wild (1998), The estimation of an average cost frontier to calculate benchmark tariffs for electricity distribution. Working Paper No. 9803. Socioeconomic Institute, University of Zurich.

Filippini, M., J. Wild (2002), Berücksichtigung von regionalen Unterschieden beim Benchmarking von Stromverteilnetzen. Zeitschrift für Energiewirtschaft, Vol. 26, pp. 51-59.

Finsinger, J., K. Kraft (1984), Markup Pricing and Firm Decisions. Journal of Institutional and Theoretical Economics, Vol. 140(1), pp. 500-509.

Fried, H.O., C.A.K. Lovell, S.S. Schmidt (1993), The Measurement of Productive Efficiency. Oxford Press, New York.

Fritz, W., K. Lüdorf, H.J. Haubrich (2002), Einfluss von Strukturgrößen auf Mittel- und Niederspannungsnetzkosten. Energiewirtschaftliche Tagesfragen, Vol. 6, pp. 385-387.

Fritz, W., C. Zimmer (2004), Bedeutung von Struktureinflüssen beim Netzbenchmarking. Energiewirtschaftliche Tagesfragen, Vol. 5, pp. 320-323.

Giles, D., N.S. Wyatt (1993), Economies of scale in New Zealand electricity distribution industry. In: Phillips, P.C.B. (Ed.), Models, Methods and Applications of Econometrics.Blackwell, Oxford, pp. 370-382.

Haubrich, H.-J., C. Zimmer, W. Fritz, S. Mollemeier (2002), Preise und Bedingungen der Nutzung von Stromnetzen in ausgewählten europäischen Ländern. URL: http://www.consentec.de/a4dei.htm.

Hausman, J.A.,, T.J. Tardiff (1995), Efficient local exchange competition. Antitrust Bulletin.

Jamasb, T., M.G. Pollitt (2001), Benchmarking and Regulation of Electric Utilities: Lessons from International Experience. Utilities Policy, Vol. 9, pp. 107-130.

Jamasb, T., P. Nillesen, M. Pollitt (2004), Strategic Behaviour under Regulatory Benchmarking. Energy Economics, Vol. 26, pp. 825-843.

Joskow, P.L., R. Schmalensee (1986), Incentive Regulation for electric utilities. Yale Journal on Regulation Vol. 4 (1), pp. 1-49.

Knieps, G. (2005), Wettbewerbsökonomie. 2nd ed., Springer.

Littlechild, S. (1983), Regulation of British Telecommunications' profitability: report to the Secretary of State, February 1983. London: Department of Industry.

Montebaur, A., U. vom Felde (2006), Langfristige Entwicklung von Mittelspannungsnetzen in Regionen unterschiedlicher Versorgungsdichte. Energiewirtschaftliche Tagesfragen, Vol. 4, pp.42-44.

Müller, J., I. Vogelsang (1979), Staatliche Regulierung, Baden-Baden, pp. 195-259.

Müller-Kirchenbauer, J., R. Kremp, M. Ritzau, E. Evers (2002), Vergleichen, aber wie? Energie & Management, Vol. 3, pp. 5-7.

OFGEM (2004a), Electricity Distribution Price Control Review: Initial Proposals, Document 145/04.

OFGEM (2004b), Electricity Distribution Price Control Review: Final Proposals, Document 265/04.

Peles, Y.C., J.L. Stein (1976), The Effect of Rate of Return Regulation Is Highly Sensitive to the Nature of the Uncertainty. American Economic Review, Vol. 66, pp. 278-289.

Salvanes, K., S. Tjotta (1994), Productivity differences in multiple output industries. Journal of Productivity Analysis, Vol. 5, pp. 23-43.

Salvanes, K., S. Tjotta (1998), A test for natural monopoly with application to Norwegian electricity distribution. Review of Industrial Organization, Vol. 13, pp. 669-685.

Shleifer, A. (1985), A Theory of Yardstick Competition. In: RAND Journal of Economics, Vol. 19(3), pp. 319-327.

Shuttleworth, G. (2005), Benchmarking of electricity networks: Practical problems with its use for regulation. Utlities Policy, Vol. 13, pp. 310-318.

Sieben, G., H. Maltry (2002), Gutachten zu den Grundsätzen der Bestimmung von Netznutzungsentgelten für elektrische Energie auf der Basis einer Kostenermittlung unter besonderer Beachtung der Unternehmenserhaltung. Verband der Elektrizitätswirtschaft (VDEW) e.V.

Takayama, A. (1969), Behavior of the Firm under Regulatory Constraint. American Economic Review, Vol. 59, pp. 255-260.

Train, K.E. (1991), Optimal Regulation, Cambridge, Mass., und London, Ch. 1-6 and appendix.

Viscusi, K.W. , J.M. Vernon, J.E. Harrington, (2000): Economics of Regulation and Antitrust. MIT Press, Cambridge, Massachusetts [a.o.], 3rd ed.

Vogelsang. I., J. Finsinger (1979), A Regulatory Adjustment Process for Optimal Pricing by Multiproduct Monopoly Firms. Bell Journal of Economics, Vol. 10, pp. 157-171.

Vogelsang, I. (2003): Price Regulation of Access to Telecommunications Networks, Journal of Economic Lliterature, Vol. XLI (Sep.), pp. 830-862.

Yatchew, A. (2000), Scale economies in electricity distribution: a semiparametric analysis. Journal of Applied Econometrics, Vol. 15, pp. 187-210.