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Refinancing under Yardstick Regulation with Investment Cycles – The Case of Long-Lived Electricity Network Assets

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Keywords *yardstick regulation, infrastructure investment, capital-recovery, sustainable refinancing, electricity distribution*

JEL Classification *L51, L52*

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Abstract

In the context of yardstick regulation with long-lived assets, the influence of heterogeneous investment cycles on the ability to recover capital is found to be important. The application of efficient firm standards based on historic (straight-line) depreciation given heterogeneous investment and cost cycles will cause instantaneous yardstick levels below the long-run refinancing level. The efficient firm standard will prevent capital recovery in later periods. An illustrating example from electricity distribution illustrates the relevance of the problem. Finally, two alternatives, branch average cost yardstick determination and correction factors based on the share of capital under depreciation, are discussed.

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1. Introduction

The development of active and direct competition in network industries, especially electricity distribution, is often hindered by the monopolistic bottleneck character of the infrastructure (see Sharkey, 1982). Consequently, a regulatory authority has to create mechanisms, which induce the necessary pressure on costs and prices indirectly. Extensive theoretical literature shows that this goal can hardly be achieved by cost plus regulation.[1] Alternatively, there exist numerous forms of incentive based regulation schemes.[2] The *RPI-X*-regulation (see Littlechild, 1983) is the dominant incentive scheme among the incentive based regulation methods, linking firms' prices to a general price index (*RPI*) and deducting for the expected productivity or efficiency gain (*X*).[3] Decoupling prices and revenues from firms' costs, strong incentives for cost reductions arise as the firm is the residual claimant of cost savings.[4] A special form of the *RPI-X*-regulation using cost observation and comparison of the regulated firms to reduce their private information is yardstick regulation.[5] Ideally a single firm will not influence the benchmark and will therefore have no incentive to exploit regulatory reviews for revenue augmentation as the ratchet effect would predict. At the beginning it was intended to employ some sort of mean of the total costs of all regulated firms to determine the yardstick (see Shleifer, 1985). In theory, firms would then reveal their private information and direct competition could be mimicked perfectly. However,

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[1] See Müller and Vogelsang (1979) and Finsinger and Kraft (1984). For discussions of rate of return regulation, which has analogous incentive effects see Averch and Johnson (1962), Westfield (1965), Takayama (1969), Baumol and Klevorick (1970), Bailey (1973), El-Hodiri and Takayama (1970), Peles and Stein (1976), Das (1980), El-Hodiri and Takayama (1981), Train (1991), Sherman (1992) and Bös (1994).

[2] For an overview see Joskow and Schmalensee (1986).

[3] For a theoretical treatment of how to set the *X*-factor see Bernstein and Sappington (1999). Berg et al. (2006) give a good overview of different benchmarking methods in their study for the World Bank.

[4] Some other early works on incentive regulation are Bailey (1974), Laffont and Tirole (1986), Sappington (1986), Bradley and Price (1988), Acton and Vogelsang (1989), Cabral and Riordan (1989), Train (1991). Overviews of the development of incentive regulation can be found in Crew and Kleindorfer (2002), Vogelsang (2002) and Joskow (2005). In an empirical work Ai and Sappington (2002) show the ambiguous possible impacts of incentive regulation on revenue, profit, aggregate investment or prices relative to rate of return regulation.

[5] For further fundamental work on yardstick regulation see Lazear and Rosen (1981), Nalebuff and Stiglitz (1983a,b), Demski and Sappington (1984), Mookherjee (1984), Demski et al. (1988), Auriol and Laffont (1992), Meyer and Vickers (1997).

contrary to this proposition regulators recently tend to employ an efficient firm standard to determine cost targets and prices for firms, as is currently the case for electricity distribution in Germany.[6] This may lead to serious under-recovery of invested capital when operating in an environment of heterogeneous investment cycles.

We therefore study the conditions under which yardstick regulation will lead to refinancing problems under the efficient firm standard. In electricity historic cost measures are still the most wide-spread in regulatory use. Furthermore, determining historic cost measures first and, on this basis, firm's revenues, seems appropriate to solve the endogeneity problem, which is inherent in the simultaneous determination of depreciation and revenues in yardstick regulation under forward-looking revenue setting. Otherwise, typically used economic depreciation would lead to a circularity problem, because future revenue-changes induce value- and thus revenue-changes today. Yardstick regulation in such an environment is only imaginable under very restricting conditions, e.g. when the entire investment cycle enters the benchmarking ex ante (equivalent to franchise bidding). This will be explained in more detail later. We therefore stick to classical straight-line depreciation. The most important element of our model is the consideration of variable lifetimes of assets which induce cost variations in a certain year. Unplanned asset failures and fully depreciated assets may cause deviations of a single period's current depreciation (and capital cost) from a stationary long-run depreciation level. Another way to intuitively coin this central effect is to depart from the investment cycle itself. The existing capital has to be allocated by some rule to derive meaningful cost information. This cost consists of depreciation and capital cost on remaining book value. Typically, the depreciation period is less than the maximum possible lifetime of assets. This is an important aspect, because costs then

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[6] Cf. ARegV (2012). Given the number of electricity distribution companies in many countries the introduction of indirect competition appears promising and is already partially in use, e.g. in Great Britain, Norway or the Netherlands. A sample of the number of electricity distribution companies in Europe: Spain (320), France (160-170), Norway (174), Sweden (170), Denmark (130), Finland (90), Austria (160), Germany (900), Belgium (30), UK (14), or the Netherlands (10).

may vary over time depending on how much of the total capital stock is currently under depreciation. At this point, it is important to note that firms usually operate in different geographic areas with different investment histories due to e.g. demographic development. This may cause substantially different shares of capital stock under depreciation. In addition, premature failure may increase cost heterogeneously. The typical snap-shot comparison in yardstick regulation then may lead to revenues for the whole branch, which are below the necessary level for long-run refinancing. This temporary under-recovery (or over-recovery) is not a severe problem as long as exact capital recovery over the whole lifetime of the asset is still possible. This would presume alternating phases with supra- and subcompetitive profits, which, under an efficient firm standard, will only exist under very restrictive and unrealistic assumptions.

Of course, this recovery problem will not arise in a perfectly symmetric case of homogeneous capital structures. Dropping this assumption might still not be critical. In a "sudden death" scenario, yardstick regulation will impose no problems on refinancing capital.[7] This is intuitively simple: The share of assets under depreciation is always complete and no corrective replacement is necessary, because assets are assumed to have a certain maximum lifetime T and not to suffer deterioration in the meantime. Consequently, depreciation will guarantee capital recovery over the entire asset's lifetime and all that is necessary is to adapt the capital costs according to the current average age of all assets in order to consider already depreciated invested capital.

However, the sudden-death assumption is not very realistic in environments like electricity distribution, where long-lived assets reach lifetimes of 40 to 80 years for transformers and cables respectively. Depending on the actual realization of their lifetime, asset ages can deviate

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[7] This is also known as one-hoss shay pattern. The asset does not age until it suddenly fails at a fixed and known date. Cf. e.g. Salinger (1998) or Mandy and Sharkey (2003).

significantly from their expected retirement age. This induces the yardstick distortions described above.

To derive the main conclusions of this article, we use a historic cost straight-line depreciation framework. The net present value formula taken from Schmalensee (1989) can help to describe the dilemma a regulated firm will be exposed to. With initial cost I, depreciation D, allowed rate of return r, cost of capital ρ and regulatory error ε

$$NPV = -I + \sum_{i=1}^{T} D_i \left[\sum_{t=1}^{i} \frac{\rho_t}{R_t} + \frac{1}{R_i} + \sum_{t=1}^{i} \frac{\varepsilon_t}{R_t} \right], \quad \text{where } R_t = \prod_{\tau=1}^{t} \left(1+\rho_\tau\right) \text{ and } \varepsilon_t = r_t - \rho_t .$$

As long as the regulator sets the allowed rate of return at the cost of capital, the last term vanishes and the firm receives its cost of capital and – independent of the depreciation schedule – earns its initial investment spending. The problem occurring under yardstick regulation with heterogeneous capital structures is a possible shortfall in the periods' rate bases D_t. This further spills over to cumulated payments for allowed cost of capital, because temporarily lower rate bases induce lower cost of capital payments. Whereas the optimal pricing literature mostly renounces to consider explicit competition, this article explicitly analyzes how the dependence of allowed depreciation (and prices) on other firms' depreciation (and price) allowances will influence the own rate bases, D_t, and the ability to recover investors' capital outlays. We find that firms will usually fail to recover their capital when variable lifetimes of assets lead to temporarily deviating depreciation for a subset of firms.

In general, rate-setting under yardstick competition[8] is quite an under-researched topic in regulation. This seems surprising for a long-lived investment good and given that yardstick

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[8] Yardstick competition and yardstick regulation are used interchangeably throughout the text.

regulation has become popular among regulators. Even if they do not use it explicitly, most regulators conduct less complex cost comparisons independent of the use of rate of return or price-cap regulation.

To our knowledge research has solely focused on optimal pricing and depreciation of long-lived investment goods without considering explicitly effects of (in-)direct competition so far.[9] One of the most difficult problems to solve is the endogeneity of rate and depreciation setting. As Mandy and Sharkey (2003) explained, the regulator has the choice between setting prices, setting depreciation or setting both.[10] Setting prices is standard in forward-looking schemes, whereas setting depreciation is typical for historic, cost-based approaches. Subsequently, either depreciation is calculated according to prices, e.g. with economic depreciation, or prices are set according to historic depreciation, e.g. straight line depreciation.

In the context of this endogeneity, setting prices and using economic depreciation involves some difficulty.

One of the main models investigating the welfare effects of inter-temporal cost allocation for a single firm is due to Baumol (1971). He lends from peak-load pricing to find cost shares and accordingly depreciation. An interesting aspect in this article is an effect deriving from the depreciation schedule he uses, economic depreciation, which dates back to Hotelling (1925). He defines economic depreciation as the value difference of an asset over a certain period. Thereby, “The value of a machine and that of a unit of its output are interrelated, each affecting the other.” (Hotelling (1925), p.353) Prices depend on the value of the machine and the value of the machine itself depends on market conditions. Both are interrelated by time, rate of interest, operating cost, useful life and scrap value. Depreciation then is calculated respecting these characteristics and

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[9] Crew and Kleindorfer (1992) and Salinger (1998) e.g. investigate the effect of competition on optimal depreciation schedules and pricing assuming a rather implicit and exogenous variation of competitive intensity.

[10] Latter ends with the result of potentially deviating rate of returns relative to the target rate, one of the research objectives of this article.

simultaneously optimizing asset usage. Based upon this interrelation, Baumol finds that a decrease in market prices would then lead to an increase in depreciation and consequently raise prices today to guarantee capital-recovery.

At this point, the endogeneity problem of yardstick regulation with economic depreciation becomes evident. Independent of how low or high prices are set in the future, an according high or low depreciation today would compensate firms today. Price setting becomes to a certain point arbitrary, where no meaningful cost comparison is possible in the short run. A theoretical resolution to this problem would obviously be the determination of the yardstick over the whole anticipated investment cycle of all firms using information on customer needs. In practice, this is barely possible. Regulators therefore typically resort to the second option given by Mandy and Sharkey (2003) and set prices based on some (arbitrary) depreciation schedules. Following Schmalensee (1989), arbitrary depreciation schedules can be interpreted as economic depreciation in the sense that in a regulated environment, the regulator sets a depreciation schedule and then adapts prices accordingly (this is his "invariance proposition").[11] This exactly may lead to the described violation of cost-recovery, when yardstick regulation is in use.

Apart from this, there has been a great deal of research focussing on investment incentives under different cost measures and different depreciation schedules. Burness and Patrick (1992) discuss back- and front-loading incentives under rate of return constraint. For rates greater than cost of capital, they discover a back-loading incentive. For return rates set exactly equal to the cost of capital, they replicate Schmalensee's invariance proposition and the timing of cost coverage (the depreciation schedule) becomes irrelevant. Rogerson (1992) shows that regulatory lag may also make a very decelerated schedule optimal, which is named the real constant schedule and which

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[11] This of course is dependent on three assumptions. The allowed rate of return is set at the cost of capital, the firm earns its cost of capital and competition is excluded. Then, "perfect regulation adjusts cash flows so that all depreciation schedules are Hotelling" (p.295). Cf. Hotelling (1925) for the origins of value-based depreciation.

exhibits constant real payments over time. Nominal and real straight line depreciation (and all other more accelerated schedules than the real constant) in comparison will lead to undercapitalization and suboptimal capital-labour-ratios. Crew and Kleindorfer (1992) analyze the impact of technological progress and expected arriving competition. They use a straight line depreciation schedule under rate of return regulation. Their assumption is that arriving competition will make recovery impossible due to technological change. As long as there is a little leeway in the technological progress at the beginning, a switch of the depreciation scheme and front-loading (equivalent to relaxing the regulatory constraint) is still possible. They further identify a window of opportunity and a corresponding point, from where on capital recovery over the entire lifetime is not possible anymore. If the regulator will not accelerate depreciation or increase the allowed rate of return, "this under-recovery will result in disinvestment in the industry, which is the competitive capital market's response to the signal of under-recovery." (Crew and Kleindorfer (1992), p.56) Another author examining the effects of competition is Salinger (1998). In a framework building on forward-looking cost and economic depreciation, he derives that "...the possibility of competition increases forward-looking costs whenever a firm must undertake sunk investments...". This is because the investor poses the question "what price is needed today to provide the incentive to invest?" (both Salinger (1998), p.157) Therefore costs are not necessarily decreased, but may increase to recover initial costs when threats like technology introduction, asset cost, competition, demand changes will or might occur. Similar to the demand effect in Hotelling (1925), which would decrease prices and consequently increase Hotelling depreciation because of loss of value, Salinger goes one step further and makes revenues dependent on market shares. As these are assumed to decrease at the advent of competition, decreasing revenues will devaluate the asset and in consequence increase current depreciation and price. Ignoring these influences would be equivalent "to understate forward-looking costs". (Salinger (1998), p.159)

Biglaiser and Riordan (2000) investigate optimal dynamic pricing under economic depreciation. They find that, theoretically, optimal pricing is also possible under rate of return regulation. Three preconditions have to be met: the allowed is equal to the competitive rate of return, the allowed is equal to economic depreciation (considering influences like real depreciation of assets, input price and operating cost changes), and capacity is replaced efficiently.[12] This is further investigated by Rogerson (2011) who examines the conditions allowing efficient cost based prices. He shows that the relative replacement cost rule (RRC) can be used to calculate user-cost and efficient prices, which (i) allow the firm to break even and (ii) are equal to the hypothetical perfectly competitive cost of renting sufficient capital to produce one unit of output. They can be used to calculate the long-run marginal cost of production therefore allowing efficient pricing based on historical cost. Rogerson does not consider different depreciation patterns explicitly, but takes a more general formulation and investigates how technological progress should alter a given pattern to match the (hypothetical perfectly competitive) user cost of capital. Mandy and Sharkey (2003) assume a one-hoss shay failure pattern and investigate the error a regulator incurs in choosing a straight-line depreciation in combination with forward-looking pricing. They also analyze static and dynamic problems of capital under-recovery with forward-looking pricing under higher regulatory review frequency. Adaptation factors for pricing paths are calculated for different price setting frequencies and dynamically for different technologies. Evans et al. (2006)

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[12] Nevertheless, Biglaiser and Riordan (2000) show that decreasing price under rate of return regulation is optimal and that initially too high but overall deficient investment may occur under rate of return regulation. This holds when some arbitrary constant depreciation rate is chosen and it should be optimal to keep old capital in its rate base indefinitely because it is infinitely lived. These assumptions are questionable, because they do not relate depreciation to maximum asset live. In their equation (13) price evolution is dependent on depreciation contained in movement equations (13) and (14), which is zero if depreciation is removed and consequently price would remain constant. The decreasing price effect they derive is best imaginable as a temporary effect, which vanishes with consideration of reinvestment at the point where maximum age is achieved and new depreciation occurs.

compare investment incentives in a real option framework under historic and forward-looking price setting regimes. They find superior investment incentives for historic cost measures.

What these articles have in common is that even though some consider competition implicitly, they do not incorporate direct comparison of companies' costs explicitly. In the context of a long-lived investment good this research focuses on, it seems of considerable importance how structural differences in investment cycles will impact the determination of depreciation and prices.[13] This is the aim of this article. We show how a point-wise minimum operator will necessarily lead to refinancing problems of firms in the long run if investment cycles do occur.[14] It still remains an interesting and yet unresolved question how prices and depreciation under yardstick regulation can be set to follow customer valuation and equal user cost of capital, also in light of the results of this article. The remainder is organized as follows.

It is shown how the vintage structure of the capital stock under a yardstick regime influences depreciation, cost of capital employed, benchmarks and the capability of refinancing. In the next chapter, chapter 2, we first set up a simple model without any explicit age structure as a reference case. Refinancing of the capital stock is possible in this context if the amortization periods are identical and appropriate.[15] In a first extension in chapter 3, we analyse the consequences of a heterogeneous capital structure by adding 'capital vintages' to the model, still assuming a constant lifetime of capital goods ('sudden death' or one-hoss shay).We also show that yardstick regulation is feasible without discrimination or difficulties concerning long-term sustainability of network investment. Further we consider a heterogeneous capital stock with non-constant lifetime. Non-constant lifetime may either result from stochastic decay (failures) or from

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[13] This is surprising given that regulators recently have a tendency, independent whether they use rate of return or incentive-based regulation, to devote to some form of X-factor describing a productivity measure including some form of efficiency comparison.

[14] For more general research on the impact of yardstick regulation on investment see Lyon (1991), Laffont and Tirole (1993, Ch.1), Dalen (1998), Sobel (1999) and Dalen (2000). They investigate potential underinvestment (in innovation and cost reduction) caused by commitment problems of the regulator.

[15] In our analysis we focus on physical assets. We do not treat problems of the financing structure of a firm (see De Fraja and Stones (2004)).

endogenous replacement decisions or the combination of both. Whatever may be the cause, we show that under these conditions pure yardstick regulation among firms will result in a benchmark, which will not allow for capital-recovery. In a second extension in chapter 4, we consider cost of capital employed being an additional part of capital expenditure next to bare depreciation. The effect of advanced depreciation of older assets will lead to comparability problems of the cost bases and hence to unrealistic benchmarks and lacking investment even in the case of constant lifetime of assets. We further show that this problem is alleviated easily by using average asset age adaptations to the rate base. In the subsequent chapter, chapter 5, we will further illustrate the practical relevance of the problem by an empirical example of some German network operators. Their historical investment behaviour is used to derive yardsticks under an efficient firm standard over the last 30 years. In addition, advantages and disadvantages of measures like a correction based upon the share of capital stock under depreciation or the use of average instead of efficient cost standard are discussed. A final chapter concludes.

2. Simple Model: Homogeneous capital stock

Starting point of our considerations is a set *S* of firms *i*, which undergo an incentive regulation regarding their network 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 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.

- *Each firm only offers a unique network service. Its quantity remains constant over time.* Therefore price- and revenue-cap regulations are identical.
- *The provision of the network service requires only capital goods of the same type.* As a consequence, different lifetimes and amortization periods for various assets do not have to be taken into account.
- *The model is based on a straight-line depreciation scheme.* This is the mandatory method for cost-accounting depreciation in Germany and most other countries worldwide. Also, like the BNetzA in Germany, regulators in general use cost bases derived from straight-line depreciation based schemes for benchmarking.[16]
- *There is no technological progress over time.* Thus the capital stock K, which is necessary for the efficient provision of the service, does not vary 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.[17]
- *The relevant discount rate is zero.* This surely is a quite unconventional assumption. Yet it simplifies the following discussion substantially because the present value of cash flow series

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[16] See Stromnetzentgeltverordnung (2005), § 6 (2) and (4). Here we abstain from assuming economic depreciation because of its lacking practical relevance in regulated industries. It is left for further research to investigate the potential of permitting network operators to employ economic depreciation methods in the context of benchmarking. In this context it has to be mentioned that some authors derived circumstances under which economic depreciation and straight-line depreciation lead to equivalent decision bases (net present value). See e.g. Green et al. (2002).

[17] 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. See Sieben and Maltry (2002).

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 interest payments have to be considered as well. However, this assumption is abandoned in section 4, when the model is extended to include costs of capital employed.

- *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. Consequently there will also occur no entry e.g. by rivals overtaking assets of firms having left the market.[18] Also, full usage of capacity in every year is assumed.
- *The demand side effects and gains in consumers' surplus due to sinking prices do not matter.* The problem we focus on is mainly a problem of failing cost coverage; consumers do not matter. Possible short term gains in consumers' surplus resulting from a transfer due to network operators' losses in revenue caused by a benchmark set below the network operators' own costs thus are irrelevant. In the long run firms would not be able to cover their costs and thus leave the market. This is assumed to set off any possible gains in short term consumers' surplus.

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.

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[18] For rationales of a higher risk premium and cost base for an incentive regulated firm to trigger efficient investment when the technology exhibits increasing economies of scale, costs are sunk and a more efficient replacement firm can enter the market see Evans and Guthrie (2006). For a stranded-cost context see Kolbe and Borucki (1998).

In a first simple model in addition to the previous hypothesis we further assume that the capital stock is not only a homogeneous asset but that it is also not differentiable with respect to its age structure. With an average lifetime of the asset of N years we obtain 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 depreciation 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. This is why indexing of these values over the firms i is suppressed in the equations above.

The benchmark B_t for regulation is derived as:

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

In view of the preceding we get:

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

A necessary condition for sustainable network operation is however:

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

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

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

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

or equivalently:

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

This result is simple and corresponds to the practical regulatory rule that the depreciation period should correspond to the technical lifetime. Each firm is able to cover its investment needs of each period by its revenue derived from benchmarking.

Next we will show that this rule will lead to sustainability problems when the heterogeneous age structure of the capital stock is considered. This precisely occurs when firms are heterogeneous with respect to their age structure and asset lifetimes are variable.

3. Model extension I: heterogeneous capital stock

In reality the capital stock of firms is not homogeneous. Instead, it consists of different assets with different acquisition or commissioning 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 commissioning 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 into account. Consequently the corresponding cost base of period t is:

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

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

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

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:

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

Investments undertaken in year *t-1* will hence only be added to the capital stock in the following year *t*. Reference for the replacement rate $\delta_{\tau,i}$ 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 $\delta_{\tau,i}$, the following identity then has to be satisfied:

$$\sum_{\tau=1}^{N_{\max}} \delta_{\tau,i} = 1 \qquad (15)$$

Moreover, all $\delta_{\tau,i}$ have to be nonnegative of course. Whether the $\delta_{\tau,i}$ result from an exogenous aging or failure process or from an optimizing calculus of the asset owners, is not of primary importance for the subsequent considerations.

Possible distributions for $\delta_{\tau,i}$ are illustrated in figure 1. Obviously in all cases but the most simple one the mean lifetime differs from the maximum lifetime. The only exception is the case of a constant and deterministic lifetime (depicted upper left). Below we will start discussing this simple case and subsequently the variable lifetime models.

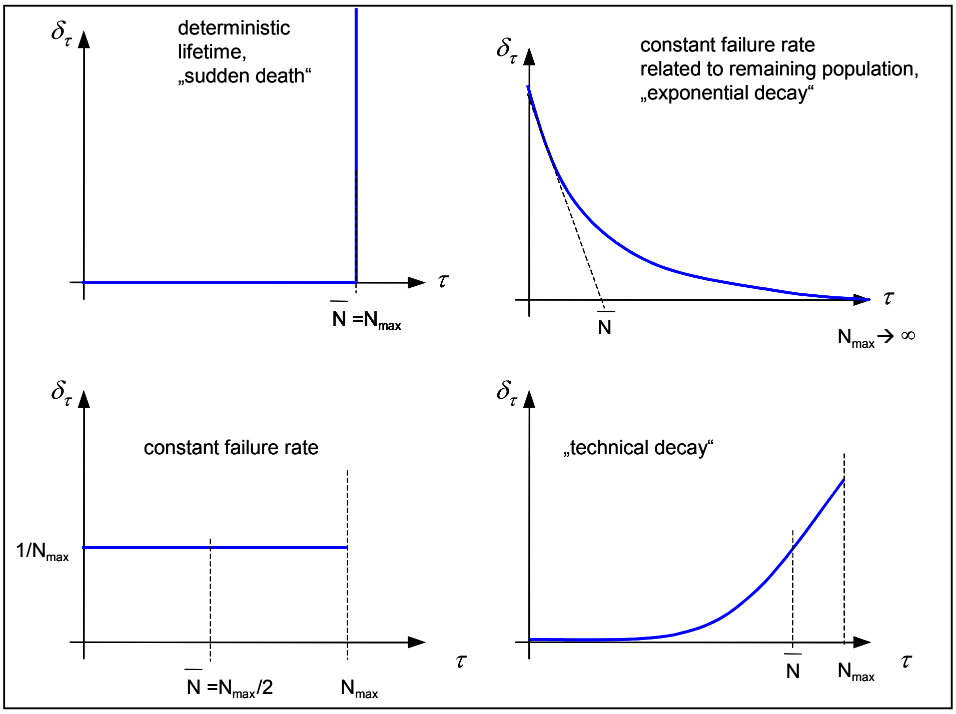

Figure 1: Different failure patterns

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* under efficient firm benchmarking results from the constraint

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

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:

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

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

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

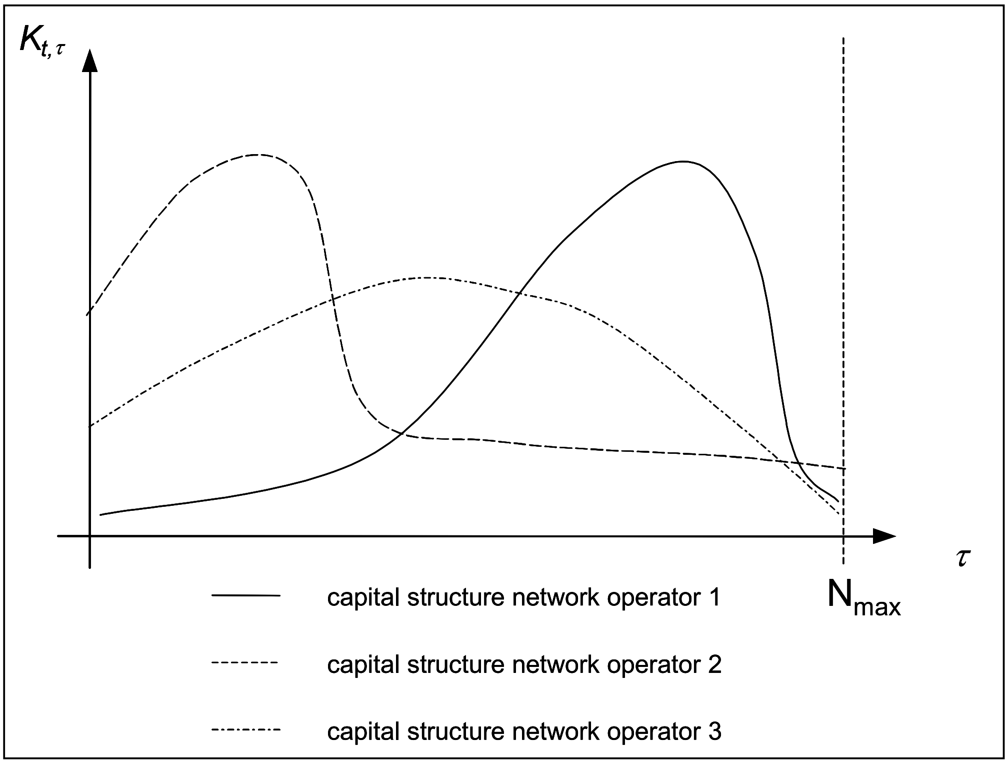

Figure 2: Companies with different capital structures

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) investment needs can be derived as:

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

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

If the initial capital stocks for the different firms vary (see Figure 2), the annual investments will as well. 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 occur that:

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

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

To determine profits or losses a look at the firm's balance sheet is helpful, from which incurred losses or profits can be 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.

- Diminution of the asset base corresponding to 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 the firm will realise losses if reductions on the asset side will exceed additions, formally:

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

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 are solely based on depreciation. Given equation (19) one obtains 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.

2. **Variable lifetime of capital vintages**

In practice it is unlikely 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 often be 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 exemplified 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 principally possible:

- $A = \overline{N}$: *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 avoiding the situation of having to replace production facilities before the end 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 firms' profit in all cases. Equation (12), nevertheless, has to be extended for the firm's amortization and expenses:

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

Here the second term $\delta_{\tau,i} (1 - \tau a) K_{t-\tau+1,i,1}$ 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.[19] Defining the replacement rate $\tilde{\delta}_{\tau,i}$ with respect to the residual capital stock

$$\tilde{\delta}_{\tau,i} = \frac{\delta_{\tau,i}}{1 - \sum_{\tau'=1}^{\tau-1} \delta_{\tau',i}} \qquad (27)$$

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

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

Or equivalently:

---

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

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

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

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

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 plus extra depreciation accounting for premature failure. Whereas 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. In contrast, 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 and thus the third term will be of considerable relevance. Hence the individual capital structure always has an influence on effective costs even under the assumption of structurally comparable firms which are in addition of identical efficiency. Obviously, this result holds also for any value A lying between the extreme points considered.

The basic benchmarking relationship (16) then still holds, but from

$$B_t \le C_{t,i} \qquad (30)$$

follows that the set S of all firms (with different vintage structures) can be separated into two disjoint, non-empty sets:

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

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

4. Model extension II: cost of capital employed

So far, the analysis has ignored the fact that firms also have to pay interest on their productive capital. This cost of capital employed has to be considered as well as depreciation, because it will influence the cash flows and the balance sheet of the network operator[20]. Including cost of capital employed will change the results obtained from the analysis conducted solely including depreciation as follows.

As before (see equation (16)) the benchmark is set by the cost of the network operator with the lowest cost level:

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

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[20] Inflation – thought of as general price increases or specific price increases of assets – analogously affects the cost base but with altering signs. No additional insight is generated by explicitly modelling inflation and it is therefore sufficient to model the cost of capital employed.

Considering cost of capital employed, the interest payments have to be added to the cost base (17) leading for the case of „sudden-death“ to[21]:

$$C_{t,i} = aK_{G,t,i} + \kappa \sum_{\tau=1}^{A} (1 - a\tau) K_{t-\tau+1,i} \tag{32}$$

The second term describes the costs of the capital employed in period t with interest rate κ. No differentiation is made between debt and equity, in line with the Modligiani-Miller theorem (Modligiani and Miller 1958). Interest payments are only due on the capital in use, as is common business practice, which is also reflected by regulatory definitions of the allowable cost base. Depreciated capital is assumed to be recompensed sufficiently and thus can be neglected. Consequently, employed capital in period t consists solely of the remaining balance sheet capital stock $(1 - a\tau)K_{t-\tau+1,i}$ of each vintage τ. The interest rate to be paid on the capital employed is given by κ and assumed to be positive and constant.

If regulation is to be sustainable, exogenous and non-influenceable factors must not lead to different costs for firms of equal efficiency. Otherwise, the benchmarking will lead for some firms to revenues which undercut the incurred costs, making refinancing based on these benchmarks impossible and thus the system insustainable (see above).

Yet, transforming (32) making use of (11), (18) and of $A = N_{max}$, shows that costs in the present case depend on the average asset age:

$$C_{t,i} = (a + \kappa) K_G - a\kappa \sum_{\tau=1}^{A} \tau K_{t-\tau+1,i} \tag{33}$$

This may be written as:

$$C_{t,i} = (a + \kappa) K_G - a\kappa \bar{\tau}_i K_G \tag{34}$$

with the average asset age

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[21] We assume the cost of capital employed to be calculated on a balance sheet basis.

$$\bar{\tau}_i = \frac{1}{K_G} \sum_{\tau=1}^{A} \tau \, K_{t-\tau+1,i} \qquad (35)$$

The older the average asset age, the more of the investments have taken place in periods with higher τ and the more of these early investments are written off already. Consequently, compared to the reference case of an entirely new capital stock – the positive term – the costs gradually diminish as the network operator's assets grow older and the depreciated part of the capital stock – the negative term – gains more weight.

As a consequence of equation (34), the firm with the oldest asset base will set the benchmark:

$$B_t = (a+\kappa)K_G - a\kappa \, K_G \max \bar{\tau}_i \qquad (36)$$

Obviously, for all firms *j* with a lower average asset age $\bar{\tau}_j$, one has:

$$C_{t,j} > B_t \qquad \forall j \; \bar{\tau}_j < \bar{\tau}_i \qquad (37)$$

and consequently those will earn less than their cost. As in the previous case, this lack of revenue may not be compensated in other periods, because the own costs always form an upper bound to the revenues. Thus the simple benchmarking rule will lead to unsustainable results, as soon as firms differ in their average asset age. To be more precise: investment cycles are not by themselves an obstacle to the correct functioning of the benchmarking procedure. But as soon as investment cycles are not identical for all firms, the benchmarks obtained will not lead to cost recovery.

This result obviously may be generalized to the case of variable lifetimes discussed in the previous section.

5. Illustration of refinancing gaps and alleviating cost standardizations

In this section we illustrate the impact heterogeneous investment cycles can exhibit on capital recovery under yardstick regulation. Cyclical differences are estimated by the means of investment data for seven German network operators. In addition, the annual mean of investments of the whole branch is given. As the data is confidential firm names are as well. Following figure shows the evolution of investment over the last 70 years. The graphs depict investment of each firm in percent of the firm's total capital stock.[22]

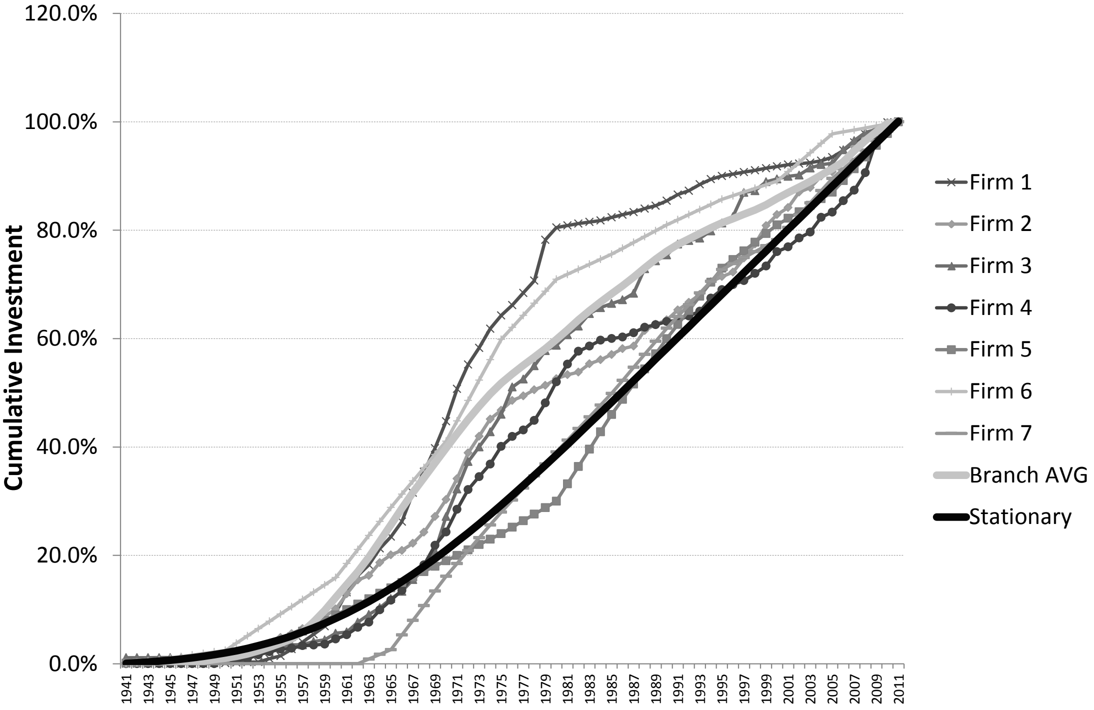

Figure 3: Distribution of cumulative investment

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[22] The investment time series contain information on the medium voltage cables, because of the most reliable data availability. Investments in other asset classes like transformers is – to our knowledge – analogous, because of budgets being distributed in more or less fixed proportions. Further, much of the installations is connection of new areas, where assets of all classes are necessary.

It is obvious from the picture that the seven companies in the sample invested much less than the branch average until the mid-sixties and then invested more during the subsequent decade. Afterwards, the seven firm average parallels more or less the branch average. These investment time series allow a rough approximation of current yardstick revenues. The main cost driver is the current capital stock under depreciation, which shall serve as a proxy for current cost. We assume the depreciation horizon to be 40 years for all companies and replacement age to be set at 69 years.[23] This allows us to consider the last 30 years for a yardstick assessment. The capital stock under depreciation then covers the last 40 of 69 years. In a stationary environment, a firm would thus have 77% of the total capital stock under depreciation, including premature failure.[24] The remaining 23% would then be depreciated already. This stationary replacement is depicted in Figure 4 as the horizontal solid black line. Finer lines are associated to the firms cost evolution. The dashed solid black line shows the current yardstick assuming the efficient firm standard whereas the solid bright line shows the branch average. Heterogeneous investment cycles lead to substantial deviations from the stationary reinvestment.

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[23] We use Weibull distribution assumptions to characterize the failure behaviour. Cf. Appendix for detailed failure assumptions. Cf. Obergünner (2005) for cost data with an assumed 10€ penalty per kWh lost. Replacement age then simply results in an expected cost minimization with expected cost from premature failure being about 20% of replacement investment cost.

[24] Under the given assumptions the stationary age as a non-linear progressively decreasing function of time can be derived. This distribution is used to calculate the share of capital stock under depreciation, which results in about 77%.

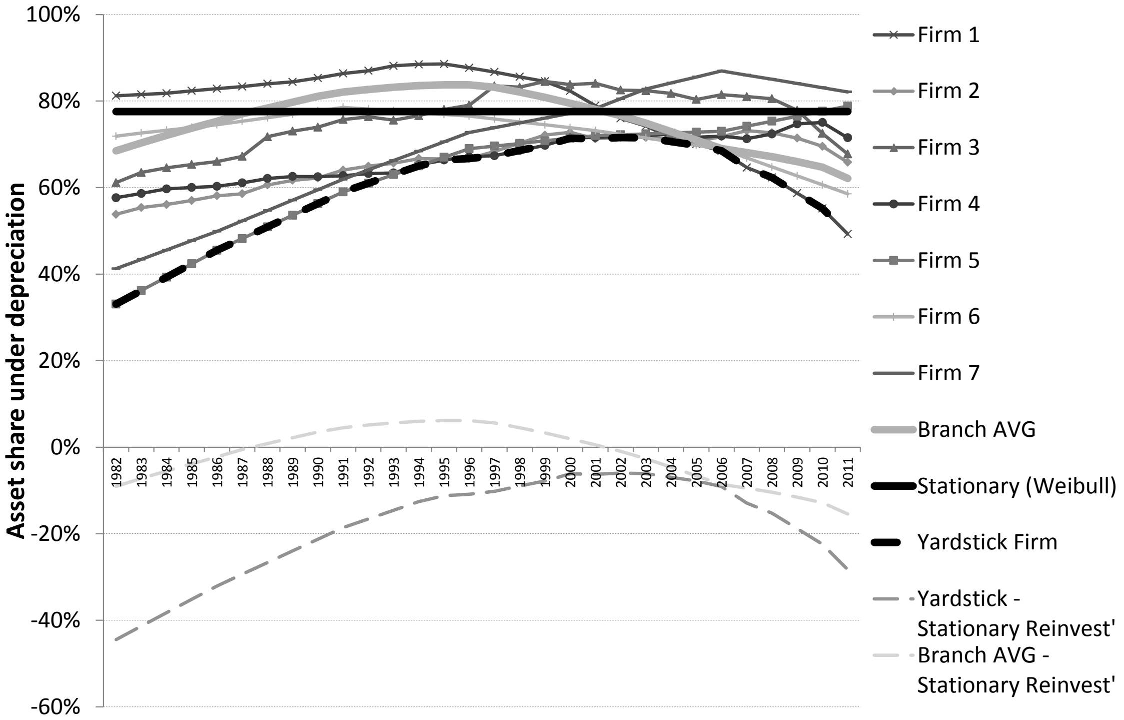

Figure 4: Cost evolution over the last 30 years

The lower two dashed lines show the difference of the yardstick firm’s cost and the stationary reinvestment cost (dark gray) as well as the difference between the branches’ average cost and the stationary reinvestment cost (light gray). In the former case, at the extreme the revenue in a single year falls short of more than 40%. At the end of the observation period this difference amounts again to similar values of about 30%. On average the difference between the stationary and the yardstick asset share under depreciation is about 18%. This is impressive and demonstrates that serious capital-recovery problems may occur in the future, if the German regulator stays with the efficient firm standard. In the latter case, the branch average of companies in Germany is taken and compared to the stationary reinvestment case, which reduces the difference significantly to less than 2%.

6. Conclusions and discussion

This paper investigates to what extent yardstick regulation allows for capital-recovery with investment cycles under a pure “efficient-firm-standard” benchmarking. Sources of and conditions for distortions are identified and analyzed in detail.

The heterogeneity of asset structures resulting from variable lifetimes has been identified as a main problem of yardstick regulation comprising capital costs. Network operators with relatively old assets will set the benchmark since they partly produce ‘without costs’. In contrast to the wide-held belief that average-age cost corrections suffice to guarantee refinancing of regulated companies operating long-living assets, it is now obvious that the asset age structure heterogeneity is decisive for refinancing.

It has been shown that the choice of an average cost standard alleviates much of the problem in an empirical illustration.

This is already the first of two possible corrections of benchmark distortions. First, a regulator could use branch averages instead of an efficient firm standard following the original proposition by Shleifer (1985). This would change equation (16) to $B_t = \frac{1}{n}\sum_i C_{t,i}$ securing this alternative, average cost benchmark to always exceed the efficient firm benchmark (or at least being equal), $B_{AVG,t} \geq B_t$. Implementing this rule will secure survival for at least as many firms as under efficient firm rule yardsticking.

Regarding depreciation this would even solve the problem: Given the assumption of identical $N_{\max}$ for all firms n and assuming constant cycles, we can sum costs of each period over t showing that $\sum_t B_t = \sum_t \frac{1}{n}\sum_i C_{t,i} = \frac{1}{n}\sum_t\sum_i C_{t,i} = \frac{1}{n}\sum_i\sum_t C_{t,i} = \frac{1}{n}\sum_i K_G = \frac{1}{n} n K_G = K_G$. Capital costs linearly depend on the capital stock. Therefore they do not cause any additional distortions.

The standardization of depreciation periods will then fix capital costs over the entire investment cycle to an identical level for all firms.[25] This will suffice to guarantee refinancing of network operation.[26] When, in contrast, different depreciation periods are allowed, full cost-recovery of the whole branch is at risk.[27] Furthermore, the fact that the transfer of money over time is costly is a serious problem of this approach. If a firm has either high or low investment compared to the branchwide average, banking will be necessary. If conditions for borrowing and lending rates differ substantially, this will impede refinancing. Additional pressure may as well result from long-lasting corporate liquidity needs due to low equity-to-debt ratios following longer phases of relatively low benchmarks.

Sticking to the efficient firm standard and introducing "share of capital under depreciation"-factors is a second alternative. This factor can be determined using equation (29). The relative share of the second and the third summand of total costs determine the deviation from a cost level independent of the capital structure. The latter is given by the first term and is (per assumption) identical for all firms. The regulator then is confronted with the problem of determining a ratio of the second and third term. He can fix a ratio of both terms for comparability reasons. A natural candidate would be a ratio based on the asset age structure of stationary replacement given fixed maximum lifetime. The amortization period could be set at expected lifetime given an optimal replacement age.[28] A high share of old assets will increase the second term whereas a high share of young assets will increase the third term of equation (29). Regarding depreciation a simple standardization to correct for higher density masses of capital in the second or third term with

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[25] If this is not the case, a firm with longer depreciation periods will have absolutely higher capital costs. Cf. Schober and Weber (2013).

[26] This is also suggested by the residual of only 2% in our application. The residual is not equal to zero because of the short comparison period smaller than $2T$.

[27] Increasing the number of firms may make the confidence interval around the stationary replacement cost smaller. This may make it easier for the average firm to recover its costs. Recently, alternative cost standards have e.g. been discussed by Lowry and Getachew (2009). This may comprise e.g. relatively robust quantile benchmarks, though none of the approaches eliminates all sources of distortions stemming from firm heterogeneity.

[28] Cf. Weber et al. (2010).

regard to the reference case will suffice to control for heterogeneous investment cycles. The regulator can then compare costs.[29] Regarding capital costs, the regulator would still have to account for average asset age of remaining stock under depreciation – also with regard to the reference case – as in equation (34).[30] All of the necessary transformations are linear in nature leading to precisely calculable standardization operations.

This approach incorporates the advantage of directly determining a yardstick which enables refinancing in lieu of having to rely on an evening out over several regulatory periods as the aforementioned approach. It directly addresses the firm's investment cycle as the main driver of cost distortions from a longitudinal perspective. Scaling factors adjust costs to a level considering heterogeneous investment cycles for all firms making direct comparisons immediately possible, independent of the current position in the respective investment cycle. The obvious disadvantage of this approach is data availability. Typically, the regulator will not dispose of the necessary historic data and thus be forced to engage in a process of costly manual post-collection of missing data. To the contrary, the BNetzA proposal and current procedure of simply recalculating capital costs by using current asset values and standardized amortization periods for all types of assets to cope with the long-lasting asset nature falls short of the mark. It uses identical information for revenue allowances being based on the share of assets under depreciation as an approach simply standardizing amortization periods. A substantial advantage therefore cannot be seen with regard to the solution of the problem of heterogeneous capital structures. The regulator thereby still takes the risk of considering only firms' heterogeneous capital stock shares currently under depreciation (this time at new amortization periods). As a consequence similar distortions will occur, if no correction factor is applied with regard to the share of capital under depreciation.

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[29] This presumes that one-off depreciation for premature failure is not feasible.

[30] This presumes again constant maximum lifetime or, in other words, a normalized maximum asset lifetime for a given share of maintenance.

Which of the two mentioned alternatives might be superior depends on the involved trade-offs. On the one hand, gathering information is costly, on the other, banking as well as financial pressure lasting on network operators may be similarly costly. The answer to this question is beyond the scope of this article. Regulators should, however, be aware of problems related to investment cycles when using yardstick regulation, especially when applying an efficient firm standard. Nevertheless, the efficiency properties of yardstick regulation helping the regulator to reduce ratchet effects still make it worth thinking about its use despite possible heterogeneity of operators. Shleifer (1985) found firms to produce efficiently independent of the yardstick level. He proposed several yardstick functions, with the independence of own costs and own revenues as the sole condition to be met . Whether the regulator applies an average cost or an efficient firm standard makes no difference concerning efficiency incentives. The level of the yardstick is merely a question of the distribution of efficiency gains: More conservative rules will leave higher rents to the firm, but cost reducing effort will be the same.

Another controversial subject supporting the use of average cost standards is the reliability of benchmarking and benchmarking methods used for yardstick regulation. If one of these is inexact, potentially substantial amounts of remaining unobserved heterogeneity in firms' costs risks to be attributed to its inefficiency. These may stem from e.g. unobserved differences in the firm's service obligation that it is not responsible for or from methodological inexactness. This would distort efficiency scores of the respective network operators as well as average efficiency levels. A recent paper by Growitsch et al. (2012) e.g. compares average efficiency estimates attributing unobserved[31] firm specific heterogeneity, first, to inefficiency scores and, second, to a separate firm-specific fixed dummy for a sample of Norwegian companies. In their paper average efficiency rises from about 60% to about 90%, showing that eventually there are much persistent

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[31] This is assumed as time-invariant and therefore is measurable.

influences that a network operator maybe cannot be blamed for.[32] There is also a multitude of benchmarking methods at the disposal of the regulator leading to potentially different results. For a comprehensive overview of the different methods we refer to a study prepared by Berg et al. (2006). Jamasb and Pollitt (2001) provide an excellent overview of by then completed studies.[33] Future research should investigate the multiple interdependencies between endogenous replacement decisions and the cost base applied for benchmarking. This could shed more light on the optimal allocation of dynamic investment and cost allocation under yardstick regulation. Further, efficient pricing and depreciation in a dynamic yardstick environment does not seem to be fully understood.

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[32] Recent papers contributing to this discussion also include Farsi et al. (2006), Bagdadioglu and Weyman-Jones (2008), and Kim and Schmidt (2008).

[33] Cf. also Shuttleworth (2005).

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Appendix

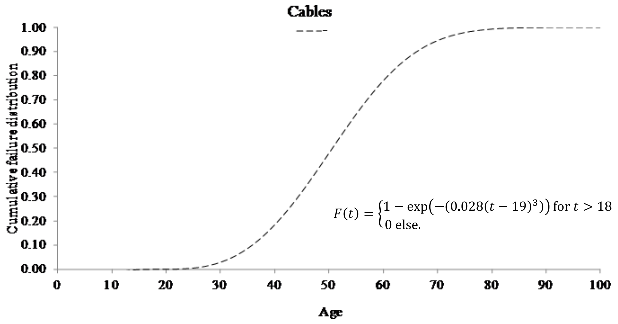

Figure 5: Cumulative failure distribution of medium voltage cable