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EFFICIENCY FACTOR'S DETERMINATION (X FACTOR)

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1 Introduction

The Energy Regulatory Regional Association (ERRA) integrates 23 regulatory authorities as full (and 5 as associate and partly extra-regional) members in the region of Eastern Europe / Asia. Regulation of the electricity networks in this region has dynamically evolved, not least because many countries in the region have undergone privatisation and industry restructuring processes in recent years. In this context, especially incentive mechanisms are an instrument to regulate the tariffs set by private network companies in a market environment.

Against this background, KEMA assists ERRA's Tariff/Pricing Committee in drafting and completing an issue paper on the Efficiency Factor's Determination (X factor). Thereby, the role, data requirements and computation principles for setting efficiency increase requirements (X factor) for price control purposes, experience from selected countries as well as practical calculation examples are in the focus. In addition to the conceptual part, and after agreement with ERRA, KEMA has prepared and sent a questionnaire to all ERRA members in order to investigate the status quo regarding the application of incentive mechanisms and benchmarking in these countries. The regulatory responses to questionnaire provide a valuable source of information that will be considered in the formulation of our conclusions.

The present draft of the paper deals with the following issues:

In the preceding chapter 2, the elements of a cap regulation are explained with special regard to the role of the X factor within a cap regulation. Since X factors can be determined by applying different methods, these methods are explained in chapter 3. Chapter 4 contains details of the computational background and the quantitative application of benchmarking instruments. Chapter 5 provides insights in international experiences, focusing on countries which exemplify the practical application of efficiency analysis within an incentive regulation framework. Chapter 6 provides practical examples for establishment of X factors using two methods: "building blocks" and "total cost".

The results of this survey based on the KEMA questionnaire are given in chapter 7. Explanation of the outcomes and conclusions are provided in chapter 8. Appendix 1 to 3 gives further theoretical information on parametric techniques, the Tornqvist and Malmquist index.

2 Cap Regulation and Role of the X factor

2.1 Price-Cap Elements

2.1.1 Price-Cap Formula

This paper deals with the advantages of a price cap system and on the ways implied by setting an X factor, or efficiency expectation parameter, out of the price cap regulation scheme. In observance to the Terms of Reference, price caps as such are first introduced in what follows.

The main advantage of a price-cap system lies within the strong incentives it generates for higher productive efficiency. Price-caps unlink prices from actual costs by imposing a predefined change in prices over the course of a fixed regulatory period. The annual change in prices is determined by the X factor. If the utility manages to reduce its costs in excess of the X factor, it earns additional profits and conversely, if it performs worse than the X factor, it earns less profit. This is the basic incentive provided by the price-cap system.

Economic theory predicts that maximum efficiency is achieved under **perfect competition**. One of the main features of a competitive market is that no single company can influence the observable market price. Each company's profit is then, amongst others, determined by the extent to which this company is able to operate more efficiently than its competitors. In the context of regulated monopolies, similar incentives can be created by setting the allowed price on an exogenous basis i.e. independently from actually incurred costs. Given that prices are fixed, ceteris paribus, operating at higher productivity levels i.e. producing the same level of outputs at lower costs will drive up the company's profits.

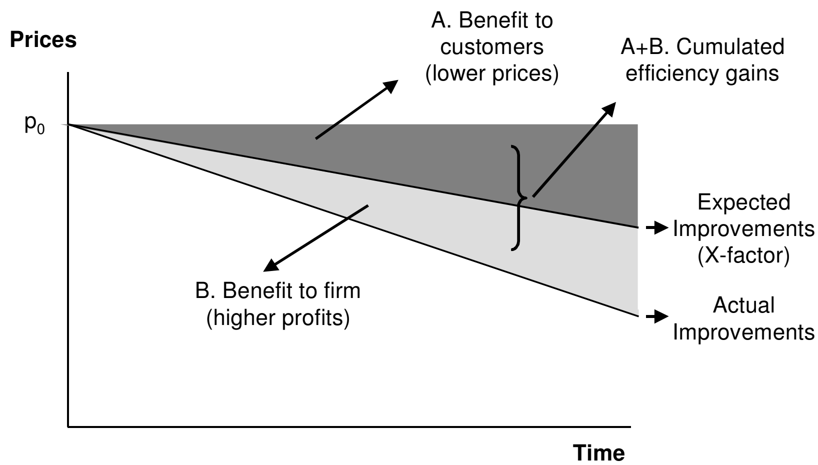

Figure 1 *Simplified representation of the incentives provided by the price-cap system. Consumers enjoy gains (represented by area A) due to a reduction in the initial price P_0. The utility retains extra profits due to cost savings in excess of the Xfactor (area B). For society as a whole, efficiency savings are given by the area A+B.*

The main difference between price-cap regulation and traditional rate-of-return regulation is that under the former system, prices are no longer directly based on the company's actual costs. At the one extreme, under a pure rate-of-return scheme, prices would be set on the basis of the company's actual costs. This provides no incentives for higher productivity. The other extreme is to completely unlink prices from actual costs; this provides very strong incentives for productivity improvement. Price-cap systems are located somewhere between these two extremes. That is, prices and costs are detached from each other, but not to a full extent; there still remains some interdependency.

In practice, the regulator sets prices not on the basis of the company's actually incurred costs, but rather on a level of cost that the regulator considers efficient. The difference between actual costs and the regulatory estimation of efficient costs is reflected in the X factor. The X factor applies for a given number of years (the regulatory period) and determines the annual change in prices in such a way that prices move in line with the anticipated efficiency improvements. Through the X factor, consumers directly participate in the expected cost reductions in the form of a lower price.[1] On the other hand, the company will also benefit as long as it manages to reduce its costs in excess of the X factor. The residual cost savings can then be retained in the form of higher profits.

[1] In principle, prices are expected to decrease over time i.e. the X factor is positive. However, in some cases the X factor can be negative i.e. the price-cap results in a price increase. This may be the case if initially, prices were not at cost-reflective levels or there is significant need of new investments during the regulatory period.

The length of the regulatory period and the level of the X factor are the two milestones in the price-cap system. Typically, prices are also adjusted for inflation in recognition of the fact that the cost of goods and services used in the production process will change over time and that this change in price levels is generally not controllable by the utility. In its most general form, the price-cap formula is then given by:

$$p_t = p_0 \cdot (1 + CPI_t - X)^t$$

Here, p_0 is the initial price, p_t is price for year t of the regulatory period, CPI is the consumer price index, and X is the annual price adjustment. By limiting the duration of the regulatory period, the regulator can make sure that differences between actual productivity improvements and anticipated improvements are retained only for a fixed period. In practice, a regulatory period of between three and five years is deemed to be a reasonable compromise[2]. The inflation factor is typically the one published by statistical institutions and can be the CPI for example as well as the retail price index (RPI), or producer price index (PPI), or a combination of these with other inflation indices.

If the regulator is able to accurately predict the company's future productivity improvements, it could set the X factor on this basis. Then, the company would not earn too high excess profits while at the same time, financial sustainability of the utility would also be assured. A better assessment of the company's true productivity improvement potential can thus lead to a better balance between the interests of the company and consumers. In summary, the X factor should be low enough to leave the company with sufficient funds and it should be high enough so that consumers can also share the ongoing productivity gains. It is, however, the case that quantifying the productivity potential, and therefore setting the X factor, is seriously complicated by the regulator's sometimes poor informational position relative to the company.

Generally speaking, one may assume the company to have private (albeit incomplete) information about whether and by how much it could improve on its efficiency. This information is not available to the regulator and consequently, the regulator is constrained to compute the most appropriate X factor. Furthermore, the company could strategically exploit its superior informational position by talking down the X factor – claiming for instance that it is based on inaccurate estimation and unrealistic or unattainable envisaged targets. Clearly, the regulator's ability to assess the company's true productivity improvement potential can greatly benefit the effectiveness of the price-cap system. Benchmarking analysis can play an important role in this regard.

[2] For mature industries in need of high investments, a longer regulatory period could be envisaged, for instance longer than five years and corresponding to a longer franchise system on assets such as in UK railways. This is, however, not normally the case with energy-related industries.

2.2 Price-Cap Strategies

2.2.1 Classification

Within price-cap regulation and the problem of setting the X factor, benchmarking is an important regulatory instrument to identify the scope for productivity improvement and to consequently set the X factor. However, there are different ways to translate the results of the benchmarking analysis (and related efficiency ranking and scoring) into the X factor. One extreme would be to directly link the X factor to the efficiency score. In this case, the regulator could perform a benchmarking analysis at the start of the regulatory period and set the X factor for each company based on its efficiency score. This efficiency score represents the theoretical extent by which the company could reduce its costs down to the level of what would be considered efficient. The X factor then imposes a gradual price reduction from the initial price towards a price that reflects an efficient level of cost (including a reasonable return). If *n* is the duration of the regulatory period in years and θ is the efficiency score obtained from the benchmarking analysis, the X factor for a given company would be set such that:

$$(1-X)^n = \theta$$

The company thus needs to reduce its costs into line with or in excess of the X factor in order to maintain a high level of profitability. Furthermore, in the case of regulation of a number of companies, the efficiency score θ and therefore the X factor would reflect efficiency improvement potentials of the respective company relative to the others in the sample. This introduces a degree of competitive pressure: those companies that operate at higher productivity levels would obtain a higher efficiency score and consequently get a lower X factor.

However, the link between benchmarking analysis and the X factor can also be indirect. If the regulator feels that it can only imperfectly perform a benchmarking type of analysis, she may wish to use the efficiency score as a starting point for setting the X factor rather than imposing a mechanistic link between the X factor and the efficiency score. The benchmarking results would provide information on the range where the X factor could be located. This information can then be used as an input for the quantification of the X factor.

Until now, we have made the implicit assumption that the regulator sets the X factor at the start of the regulatory period. Alternatively, though, the regulator could choose to set the X factor at the *end* of the period, i.e. once the utility has realised its productivity improvements. This in fact takes away any uncertainty as of the level of the X factor, as the latter would then be based on actually achieved improvements. However, this approach has the disadvantage that the company get no incentive to achieve any productivity improvements in the first place as it may anticipate that these will be clawed back – not unlike the outcomes of rate-of-return regulation.

To avoid this problem, the regulator can impose limits to the level of the X factor. For example, the regulator could set an initial X factor and only adjust this if the company's profits fall outside some predetermined range. The company thus always retains part (or potentially all) of its realised improvements. In the case of multiple companies being regulated, the regulator could set the X factor on the basis of actually observed changes in the average performance of all utilities. This introduces competitive pressure, as companies that improve beyond the average would enjoy higher profits than those who perform less than average.

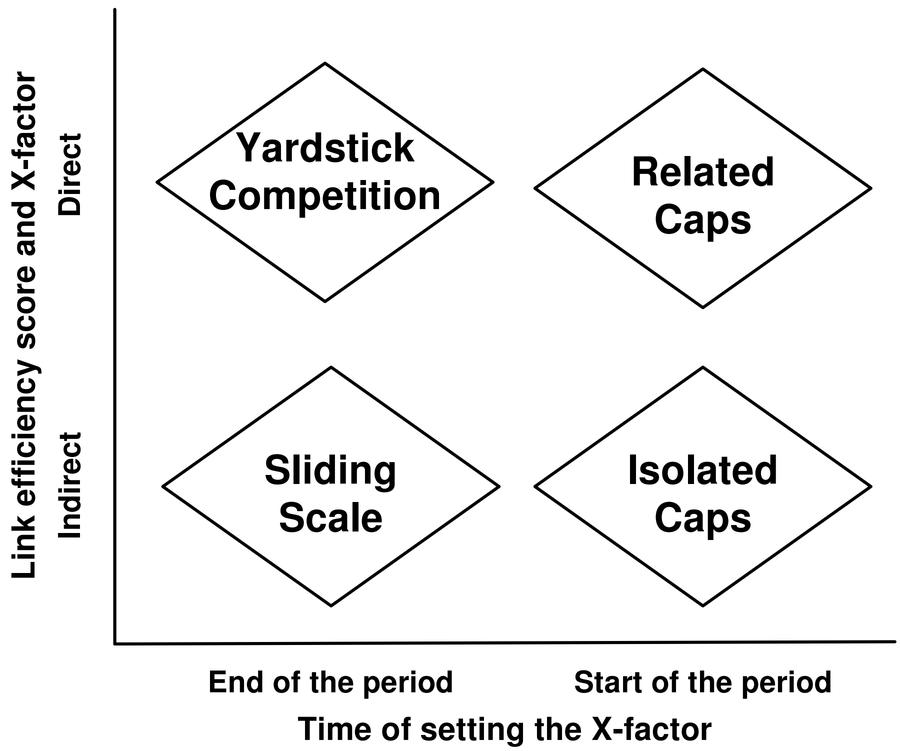

Figure 2 *Classification of price-cap strategies.*

In summary, two dimensions can be identified relating to the process of setting the X factor. Firstly, as shown on the vertical axis in Figure 2, the regulator can choose either a strong direct coupling or a loose indirect coupling between the benchmarking analysis and the X factor. The second dimension, as shown on the horizontal axis in Figure 2, is concerned with the timing of the X factor setting in relation to the benchmarking analysis. The X factor can be set at the same time as the benchmarking analysis i.e. at the start of the regulatory period, or afterwards i.e. at the end of the regulatory period. Figure 2 shows how combining the options in each of the two dimensions would lead to four possible strategies for setting the X factor. In the following sections, these strategies are explored in more detail.

2.2.2 Yardstick Competition

Yardstick competition introduces a strong competitive aspect to the process of setting the X factor. In the original definition of yardstick competition, the price for each company is set equal to the average cost of all other companies in the regulated industry. There are some variations on this theme. For example, the price can be set on the basis of the average cost of all company (including the company under consideration), or one could apply some quantity weighted average of costs to calculate the yardstick price.

Irrespective of the specific formulation, the main idea is that the company's profitability is no longer determined only by its own cost performance, but is driven by how well it manages to reduce costs relative to others. This gives a strong incentive to increase performance – similar to the incentive observed in competitive markets. If a company manages to reduce its costs by more than the yardstick, it will earn a higher profit and conversely, company that lag behind average performance will earn lower profits and possibly even incur losses. As all companies have an incentive to reduce costs, this also brings down the average cost within the industry. Thus, a continuous downward adjustment of the prices would take place whereby each company's effort to reduce costs in excess of the average simultaneously leads to a decrease in the yardstick itself.

In the price-cap context, the X factor under a yardstick competition scheme would be set on the basis of actual improvements in productivity. Thus, there is in principle no need for the regulator to make any predictions about productivity improvement potential as this information would be automatically revealed through the yardstick scheme. Also, as prices continuously track realised improvements over time, efficiency gains are quickly transferred to consumers. In essence, under yardstick competition the regulator would no longer have to set the X factor but would simply adjust prices each time on the basis of some index of average cost.[3]

In his seminal paper on yardstick competition, Shleifer (1985) noted that an important aspect of measuring the yardstick is the need to adjust for possible structural differences between companies. Setting prices on the basis of average costs suggests that companies are perfectly comparable to one another. This may not necessarily be true as there may be structural differences in the operating environment across companies. Some companies may have to deal with specific factors, which lead them to incur relatively higher costs than others. Furthermore, one also needs to take into account the multi-dimensional nature of the

[3] If the regulator needs to set prices at the start of the regulatory period, initially an estimation of the X factor can be made. At the end of the regulatory period, the X factor can be adjusted based on realised cost developments. This approach is, for example, followed in the Netherlands.

company's production process. There may be more than a single input or output factor involved in providing the regulated service. Neglecting such factors in the determination of the yardstick would disadvantage some companies and provide others with an unintended advantage. To deal with this problem, more sophisticated notions of average costs could be used. The use of benchmarking methods, which incorporate multiple input and output factors and allow to correct for structural differences, can play an important role in this process.

In addition to the comparability problem, there are two other main problems attached to yardstick competition, namely commitment and collusion (Weyman-Jones 1995). The collusion problem is related to the fact that the companies may strategically cooperate to influence the outcome of the yardstick system. For example, companies may collectively report higher costs than actually incurred in order to drive up the yardstick. The scope for collusion increases as the number of companies is smaller. Therefore, in order for yardstick competition to be effective, a large number of participating utilities is a necessary (but not sufficient) condition.

The third problem is that of regulatory commitment. Yardstick competition assumes that the regulator is committed to the regulatory contract. This means that, irrespective of the outcome, the process by which the yardstick is calculated is not changed afterwards. In principle, this should also hold in the case of bankruptcy of one or more of the participating utilities. Similarly to a competitive environment, companies who perform better then the yardstick earn exceptional profits while others that lag behind will either earn less, or even in the limit will potentially become unprofitable and eventually go bankrupt. If the yardstick system is to remain credible, bankruptcy of one or more companies should not be excluded as a potential outcome, implying that the regulator should not adjust the rules of the system ex post to prevent ill-performing companies from going bankrupt. However, bankruptcy of an electricity distribution utility has substantial social and therewith political impact. It therefore remains questionable if such (distribution) utilities would in practice be allowed to go bankrupt[4].

2.2.3 Related Caps

For yardstick competition to be fair, all companies should have the same initial scope for improvement. If this is not the case, then companies who are initially less productive than others could reduce costs more than others and subsequently drive down the yardstick. These companies would then consequently earn higher profits than companies with less initial scope for improvement. However, these profits would be the result of an unequal

[4] As far as known, proper yardstick competition for electricity distribution has only been adopted in the Netherlands. Retail suppliers have been allowed to go bankrupt in the UK and, to our knowledge, in the Netherlands as well, but not anywhere else. Distribution network operators have not been allowed to go bankrupt anywhere.

starting position and therefore not be conceived as fair by the other companies. To deal with this problem, one could assure that companies are first brought to the same productivity level. Creating this level playing field is the basic idea of the related caps strategy. The related caps strategy may thus be considered as the preparatory phase before moving to yardstick competition.

Under related caps, the regulator would set the X factor at the start of the regulatory period on the basis of an assessment of the relative efficiency of each company. Clearly, similar as under yardstick competition, the related caps strategy can only be applied in case of multiple companies regulation. Each company would be allowed a different price and X factor, reflecting its starting productivity level and improvement potential, respectively. The X factor would be directly driven by the results of the benchmarking analysis. Hence, there will be a strong degree of interconnection between the X factors and prices for different companies. The ability to compare companies in a proper way, i.e. account for the multi-dimensional nature of the regulated network service and incorporate structural (accounting) differences between companies is therefore an important precondition for the related caps strategy to be effective.

DTe, the Dutch energy regulator, published its first decision on the X factors for electricity distribution networks in September 2000. These X factors were strongly driven by the results of a DEA benchmarking report. The DEA benchmark was applied to a sample of 20 Dutch distribution utilities. As an input factor for the benchmarking, DTe chose total cost, which is the sum of operating expenditure, depreciation, and a standardised return on assets. In order to harmonise depreciation and book value data across utilities, DTE performed a backward calculation of book and depreciation values. In doing so, however, a number of assumptions and approximations had to be made. Due to the lack of detailed data, the standardisation was performed on an aggregate basis, thereby ignoring the differences in lifetime and age across asset categories. Also, as historical investment profiles were not available, a virtual annual investment profile was assumed when recalculating the asset and depreciation values.

The September 2000 decisions on the X factors led to a wave of protest and formal appeals by the industry. The main critique was aimed at the use of benchmarking as a way to set tariffs: efficiency scores from the DEA analysis were mechanically translated into X factors. The result of this was that flawed data – in particular due to the standardisation of capital costs – could lead to wrong efficiency scores and in turn, to wrong X factors. As the efficiency score of each company was in principle linked to that of the others, so were the X factors and therefore also the prices. Obviously, companies were not comfortable with the idea that their X factor and allowed income would be driven by data errors. Additionally, the fact that DTE widely published the benchmarking results did not help in this regard. As a result, the relationship between regulator and industry became increasingly hostile. On the one hand, DTE confirmed its decisions; on the other hand, the network companies refused to accept the – in their eyes unjust and erroneous – X factor decisions.

At some point inevitably, DTE had to revise its initial decisions in September 2001; the main difference with the initial decisions was an increase in the quality of data. An independent audit was performed to verify and improve the output factor data, while the CAPEX standardisation was refined by considering each individual asset and the actual historical investment profile. The data improvements led to higher efficiency scores and lower X factors. However, the companies' main critique points were still not thoroughly met, and there still remained problems with the data. DTE responded to this by initiating a special project with the objective to remove any remaining data problems. As a result, a second revision of the benchmark analysis and X factors was published in August 2002, but this did not prevent the network companies from confirming their appeals, as they did not consider DTE's corrections to be sufficient. Eventually, in October 2002, the Courts overruled the X factor decisions. However, the motivation for this decision was the fact that according to the Dutch Electricity Act, DTE should have applied a uniform X factor (instead of an individual X factor for each company) in the first place. It is fair to say that such flaw in the Electricity Act was corrected afterwards – perhaps a case of too little, too late.

Box 1 *The problem of related caps in the Netherlands.*

2.2.4 Isolated Caps

Under yardstick competition and related caps, there is a direct link between the efficiency score and the X factor. As efficiency scores directly feed into the X factors, any errors in the efficiency scores will also affect the X factors, the price, and eventually the profitability of the companies. Errors in the efficiency score can be caused by model errors and/or data errors. Firstly, model errors are concerned with invalid model specifications e.g. exclusion of relevant variables (input and output factors) or inclusion of irrelevant variables, failure in dealing with structural differences or each of these eventualities combined. Secondly, data errors refer to the use of erroneous data, for which a variety of causes may play a role. Clearly, one would like to avoid data errors as well as model errors to drive the X factors. If initially a benchmarking analysis is conducted and results are found to be wrong, the analysis may have to be rerun and the X factor reset. If such adjustments often take place, the credibility of the system will suffers. This is particularly problematic given that the X factors are interrelated: errors in the efficiency score of one company can potentially influence the X factor of other companies. This feature also makes the system vulnerable to strategic data reporting – in particular when the number of companies is small.

When there is only a single company to be regulated, or if the regulator considers the yardstick competition or related caps strategies not feasible, the isolated caps strategy may be considered. Here, the regulator sets the X factor for each company on an individual basis at the start of the regulatory period. For this purpose, the regulator may still make use of benchmarking analysis but the link between the efficiency score and the X factor would not be direct. The benchmarking results are used as an indication of inefficiency and would only indirectly influence the X factor. This has the advantage of reducing the sensitivity for data or modelling errors. Each utility would here be considered in isolation even though the benchmarking analysis may be applied to all utilities together.[5]

[5] If there is only a single firm to be regulated, an international benchmarking sample could be used. Also, the benchmarking analysis can for example be applied to the firm's regional branches (in both cases - data permitting).

2.2.5 Sliding Scale Regulation

It may be that, for some reason, the regulator cannot perform benchmarking analysis or she considers its results of limited use in setting the X factor. Lack of information about the company's true productivity improvement potential may, as discussed earlier, lead to two basic problems. On the one hand, the X factor may be set too low and the company will earn excessive profits. On the other hand, the X factor may be set too high and lead to financial viability problems for the company. Taking this into account, the regulator could decide to adjust the X factor in such a way that the company's profit varies only within a given range. Under this strategy, which is known as 'sliding scale', the regulator sets the X factor as a function of the profitability of the company (e.g. as measured in terms of its rate-of-return). If, at the end of the regulatory period, the utility's profit exceeds some predetermined band, the X factor is adjusted such that profits are brought back within this band. Conversely, if actual profits are higher than the allowed maximum, the X factor will be adjusted in such a way that these profits are brought back to the allowed maximum. A similar procedure would also apply to the minimum profit level. Between the two extremes, the X factor would not be adjusted, i.e. the utility would earn the rate-of-return as observed at the end of the regulatory period (see Figure 3).

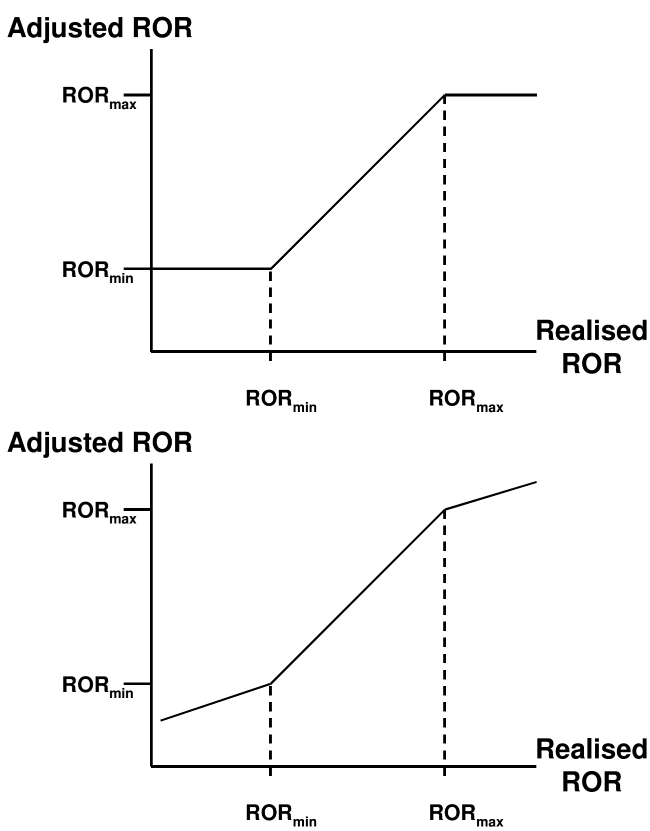

Figure 3 *Example of sliding scales with or without sharing. The X factor is adjusted based on measured rate-of-return (ROR).*

Optionally, the regulator can apply a sharing mechanism whereby the X factor is adjusted only partially in the case that profits exceed the predefined band. In this case, the company would be allowed to keep a part of the profits achieved in excess of the maximum level. Conversely, if the company earns less than the minimum profit, it will be forced to absorb part of the losses.

The sliding scale strategy assures that profits remain within certain limits, but it unfortunately discourages the company to perform in excess of these limits. The company will not pursue any further productivity improvements once the maximum profit has been attained. In the case that sharing is applied, the company only has limited incentives as it keeps only a fraction of the realised improvements. From the company's point of view, additional improvements come at a higher effort but are not necessarily associated with any rewards. Similarly, the company may well opt for the guaranteed minimum profit level (if this level if sufficiently high) rather than invest in productivity improvements. These problems become particularly relevant when the maximum and minimum of the profit range are set too low and too high, respectively.[6]

2.2.6 Evaluation

The four price-cap strategies differ in the strength of the efficiency incentives they provide. Generally speaking, efficiency incentives are stronger if the relation between price (or X factor) and costs is looser and if competitive pressure is increased. In this respect, yardstick competition provides the strongest incentive. Here, the individual company's price has no relation to its own costs but rather depends on the average of other companies. Also, direct competitive pressure is introduced. However, for the yardstick system to be fair, companies should first be brought to a level playing field of comparable productivity levels. This can be achieved by the related cap system that, in this sense, forms the preparatory phase before entering yardstick competition. Under both yardstick competition and related caps however, the direct link between the efficiency score and the X factor requires the regulator to be convinced that the benchmarking results are genuine, i.e. not driven by either modelling or data errors. If this is not the case, it may be more appropriate to adopt a less direct link between the benchmarking results and the X factor, i.e. to choose either the isolated caps or sliding scale strategy. Under these strategies, the role of benchmarking is less formal and efficiency scores would provide just an indication rather than an exact pinpointing of the productivity improvement potential.

Under the isolated caps approach, rather than directly transferring benchmarking results into the X factor, the regulator would recognise that benchmarking results are imperfect and use these as the starting rather than ending point for setting the X factor. Under the sliding scale

[6] In principle, the isolated cap strategy can be considered as a sliding scale without any minimum or maximum, i.e. linear throughout the whole range of the firm's profits.

approach, a formal buffer is imposed between the benchmarking analysis and the X factor by setting a minimum and maximum allowed level of profit. Based on this, the X factor would be set at the end of the regulatory period – reflecting the fact that the regulator cannot measure the true performance of the utility. This strategy strongly resembles rate-of-return regulation, with the notable difference that the company can now retain part of its efficiency gains (up to the maximum of the sliding scale). Note that in the extreme case, if the maximum and minimum profit levels were equal, the sliding-scale strategy would coincide with a traditional rate-of-return system.

Sliding scales are the least effective of the four strategies in terms of efficiency properties but score best in the light of financial sustainability and distributional concerns. A sliding scale puts a maximum on the profits of the company – thus limiting any distributional problems – and also guarantees a minimum profit level – thus in principle guaranteeing a minimum rate-of-return. Isolated caps are more effective in efficiency terms but if the X factor is not set optimally, this can lead to financial sustainability and distributional problems. Here, there is no limit to the return that the company could earn and thus the necessity for the regulator to set a proper X factor is increased. Related caps impose a formal link between the efficiency score and the X factor and – as a degree of competitive pressure is introduced – provide stronger efficiency incentives. At the same time, there may be serious financial sustainability and distributional problems if this X factor were set inadequately.

If the benchmarking analysis is incorrect, overestimation or underestimation of the X factor can cause financial sustainability and distributional problems, respectively. In the former case, the X factor may be too high for the company to accomplish and this may cause financial stress. In the latter case, the company may end up earning windfall profits.

Finally, yardstick competition has the most favourable efficiency incentives and is in principle comparable to competition. Its effectiveness depends on the regulatory ability to derive a proper measure of average costs. In that case, there are in principle no distributional problems as the total level of profit would be predefined and included in the measure of average costs. A drawback of yardstick competition, however, is that the continuity of service provision may be at stake, as possible bankruptcy of ill-performing or over-harshly regulated companies cannot be excluded under yardstick competition.

The analysis here suggests that there is a trade-off between incentives and rents. Here, the channels through which this trade-off takes place have been identified. When moving from sliding scales to isolated caps, to related caps, and all the way to yardstick competition, there is an increase in the efficiency properties of the regulatory strategy but also an increased risk of sub-optimally low or high profits. Making this trade-off is a matter of information: better information about the company's true productivity potential enables the regulator to opt for a price-cap strategy with superior efficiency properties and to extract more rents from the company.

In obtaining this information, benchmarking is an important regulatory tool. The more effective the benchmarking analysis, the more effective the choice and specification of the regulatory strategy – and thus the informational asymmetry solution strategy.

3 Regulatory Benchmarking (Efficiency Analysis)

3.1 Benchmarking Modelling

Benchmarking models have no fixed characteristics. They are usually composed of inputs and outputs to a production process. However, there is no agreement in either the literature or practice as of how inputs and outputs should be selected in principle. This mainly depends on the existence of a proved economic relationship between inputs and outputs, which on most empirical occasions is unfortunately not available. Therefore, the construction of input and output-based models, as well as their specification, is based on empirical analysis and try-and-error specifications. Sometimes ideal network algorithms or other knowledge-inducing mechanisms can help, but are not guaranteed to function as one-for-all fixes. Modelling will normally depend on the following practical aspects:

- what is being benchmarked
- who is conducting the benchmark
- what can be achieved, in terms of efficiency enhancements, as a result of the benchmark, and
- what theory, if any, can be used in order to make sure that the benchmark is sound.

As regards what is being benchmarked, it is essential that the output is conceptually and physically distinct from the input. An output which can also be interpreted as an input or even - in certain cases - as a non-discretionary or environmental factor would make the benchmark questionable and, in the limit, useless.

Secondly, who is conducting the benchmark matters because different parties will have different agendas with regard to the nature and outcomes of the benchmarking analysis. For instance, a regulated entity or even a company in the free competitive, market will normally want to benchmark its operating practices in depth, for instance by means of bottoms-up process benchmarking, whereas a hands-off regulatory entity which is only interested in the overall efficiency of a regulated companies will just be satisfied with top-down aggregated benchmarks for instance - this is the case with regulatory authorities in Europe. However, what can be achieved as a result of the benchmarking will also influence the formation and formulation of a model, be it a cost function, a simple set of inputs and outputs, or just a series of one-dimensional comparisons of variables.

For instance, if the company is benchmarking itself against one or more comparators, normally it will be interested in having a look at how other companies do things in order to learn from them as much as possible. On the other hand, if the result to be achieved out of the benchmarking is not just higher efficiency but lower prices to be obtained as a result of lower allowed revenue in a regulated context, then the benchmarking can be organised differently and more simply, normally to allow for top-down comparisons only. Finally, if there are any multiple theories to be used to achieve the result, then they should be availed of in the interest of methodological cross-checking. Normally, there are both engineering and economic theories being used to conduct benchmarks. Economic theories boil down to the theory of production and its dual equivalent, the theory of cost and cost functions. This normally leads to benchmarking exercises being based on the analysis of either production or cost functions, sometimes both of them, and/or hybrid variations such as distance functions and translog specifications based on log-linear first and further-order approximations. On the other hand, engineering techniques are sometimes used especially in deeper, bottoms-up benchmarking exercises dealing with process comparisons and ideal reproductions of real-world phenomena, for instance ideal network algorithms *et similia*.

This part of the report, as it will soon become clear, deals first with economics-based benchmarking models and then with engineering-based ones, typically ideal network specifications.

3.1.1 Input and Output Factor Specification

The specification of input and output factors derives from the choice of a preferred model. Inputs and outputs are normally chosen because the former contribute to the specification of the production process and the production of one or more outputs. Therefore, the inputs are the production factors and the outputs are just more or less visible production results.

Regulators normally work on production results as they are not supposed to be concerned with inputs. Regulators in the modern sense do not micromanage regulated utilities, and are therefore normally content with the outcomes of a regulated process, not with its inputs. Amongst those outputs that regulators are normally concerned with, we have cost levels. Cost levels are regulated because they are part of the revenue requirement setting exercise that regulators normally perform as part of their job. Cost levels can be benchmarked. In this case, cost will definitely be a regulatory output in the final regulatory modelling exercise, although - technically speaking and from a stricter benchmarking point of view - it will be defined as an 'input', that is, a minimisable function of a number of visible 'outputs' such as, for instance, the quantity of product delivered (say, electricity, water, gas), the number of connections being made, and so on.

The economic definition of inputs and outputs might therefore sometimes be slightly counterintuitive to the uneducated eye. However, normally speaking outputs are those things that can be observed as “results”, and inputs are those things that the regulator cannot directly observe in their making, and that have to be minimised in order for the company to behave efficiently. In almost all cases, for a hands-off regulator, this means 'costs'. More generally, inputs can be viewed physically as labour, capital, and materials and this is indeed the most economically correct way of setting up the production benchmarking problem. However, due to limited information available to regulators about (especially) input prices in a physical sense, a shortcut is taken, and all inputs are 'collapsed' into just one indicator, which is normally either operating or capital cost (or both of them where available).

3.1.2 Treatment of Environmental Factors

In addition to inputs and outputs, benchmarking models may include environmental factors. Such factors are those ones that the company’s management cannot control, or at least not in the short run, and as such they are separately considered in the estimation of a cost function or in the linear programming calculations made by some other technique. These factors have to be considered sometimes because they might still influence a company's efficiency level, and in most cases they effectively do, but still they fall outside of managerial control. Instance of such factors are regional peculiarities from a geographical and demographical viewpoint, terrain characteristics, more generally, macroeconomic parameters characterising the area or areas involved in territorial benchmarking, and so on. Environmental factors should always be taken into account when available, and should be treated differently according to the main technique being chosen for the benchmarking exercise. For instance, they should be treated differently at an econometric stage as opposed to different approaches not based on statistical techniques, such as for instance engineering network models, DEA, and the like.

3.1.3 A Formal Treatment of the Benchmarking Problem

Higher productive efficiency, or higher productivity, implies that companies produce the same level of outputs by using fewer inputs (or more outputs using the same level of inputs). Ideally, a company should operate at the highest possible productivity level. Then, the company is said to be operating at the productivity frontier. If the company is not located on the frontier, it is operating inefficiently, i.e. there is scope for efficiency improvement. This is demonstrated in Figure 4. The curve OF’ represents the production frontier i.e. the maximum output attainable from each input level. Hence, it reflects the current state of technology in the industry. Companies can operate either on that frontier if they are efficient or beneath the frontier if they are inefficient. Point A represents an inefficient point, whereas points B and C represent efficient points. If a company were to operate at point A, it would be classified as inefficient because it could well increase output to the level associated with point B without requiring more inputs. Alternatively, it could produce the same level of output using less input, i.e. produce at point C on the frontier.

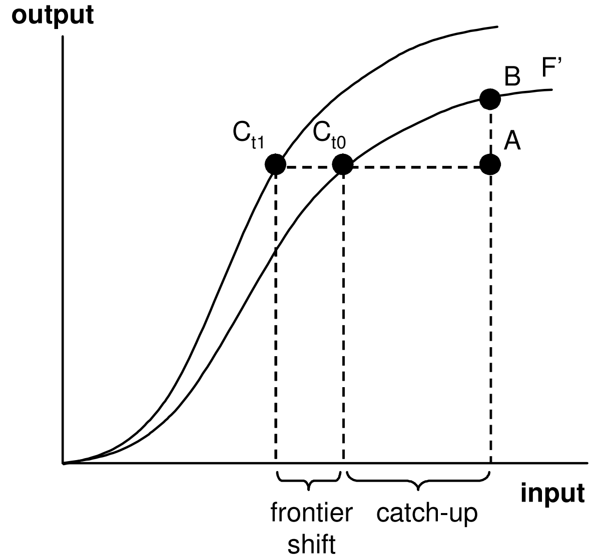

Figure 4 *Simple input and output example. Companies B and C are efficient, as they are located on the productivity frontier. Company A is not located on the productivity frontier as it is inefficient. Over time, the frontier will shift as company C improves on its productivity further.*

For measuring efficiency improvement potentials, regulators often make use of benchmarking analysis. Benchmarking, as the name suggests, is based on the concept of comparing the performance of the company to that of best practice in the investigated group of companies. Companies that operate at the productivity frontier act as the benchmark for those that are not yet located on this frontier. The frontier companies (or peers) operate at maximum productivity levels and, by definition, have an efficiency score of 100 percent (1). For other companies, the efficiency score is measured as the distance to the frontier. The further away from the frontier, the lower the efficiency score.

An important advantage of benchmarking is that it provides information on the basis of empirical data; in principle, all companies should be able to operate equally efficiently as their peers.[7] Benchmarking analysis can thus provide the regulator with valuable information that can be used for setting the X factor. However, the validity of the benchmarking analysis will be driven by the way in which the frontier, and consequently the efficiency score, is measured. In the context of electricity distribution, companies use different inputs (capital, labour) to provide different outputs (or services) to users (connections, energy, quality, etc.). While all companies use broadly the same type of inputs, some providers may use proportionately more of some inputs and less of others. The mix of inputs used depends

[7] This does not necessarily mean that the peers in the given benchmarking sample do not have any scope for further improvement. It may well be that there are other, even more efficient firms which were not included in the sample. Furthermore, there is also the frontier shift that needs to be taken into account.

upon, among other things, management practices and the operating environment. Similarly, the nature of services provided by networks varies according to the nature of consumer demands. For example, some companies may need to maintain significant network capacity to distribute electricity to a small number of consumers while others may serve a large number of consumers with a highly variable demand. Furthermore as already mentioned, there may be other factors such as climate, geography, or demography that influence the company's costs. In the calculation of productivity, the multi-dimensional nature of the production process, as well as the presence of structural differences between companies, should be taken into account. There are a number of benchmarking techniques that can be used for this purpose. These are discussed in what follows.

3.2 Benchmarking Techniques Available to Regulators

The calculation of X factors for regulated network companies involves an assessment of the likely scope for cost reduction that is compatible with both the maintenance of service quality and of financial viability. Such an assessment is usually achieved by comparing the regulated company's actual cost level with some reference cost level which the company could reasonably be expected to achieve. The process of comparing actual costs with reference costs is known as "benchmarking". Regulators normally set X factors in the future based on the outcomes of – amongst other things – benchmarking exercises and following the outcome of a consultation process with the industry.

For the individual regulated company, benchmarking involves identifying a suitable set of utilities to which the company can be usefully compared. These companies are known as "comparators". This is not a straightforward exercise because there is no company which is doing exactly the same thing as another company, since territorial companies have different output levels and output mix, and face different environmental conditions. These differences mean that efficient cost levels are unlikely to be identical for each company. However, benchmarking methodologies can be used to model some of the differences, as long as scale and other effects are properly taken into account, and non-controllable differences are not too great. It is, however, important that comparators include the most efficient reference companies – otherwise the relative performance of the regulated companies may be exaggerated, X factors may be set too low, and consumers will not get the benefits of the larger potential cost reductions which the benchmarking exercise failed to identify.

In regional networks and supply, the comparator group will include regional network companies. These companies are obviously engaged in similar activities and lend themselves to comparison. Any production/cost benchmarking exercise needs to decide what exactly is to be compared.

Cost and production benchmarking is primarily an exercise in calculating historical cost or output differentials. It allows us to establish that, in some initial year, company A is capable of reducing costs (or increasing output) by, say, 10% relative to an 'efficient' company B. This suggests that, over a five-year regulatory review period, the X factor for company A should be higher than company B to reflect the greater initial inefficiency of company A and the 'catching-up' required of utility A. X factors that are simply based on 'catching-up' allow for productivity growth based on the gradual elimination of inefficiency (the "glide path"). However, they do not reflect the scope for productivity growth based on technological improvement even for the most efficient company, that is the so-called 'frontier shift' effect (caused by an outward shift in the efficient frontier). Some assessment of this 'frontier-shift effect' needs to be made separately from the pure benchmarking exercise. Over time, the regulator will have to establish a general frontier shift that it expects from even the best companies in the industry to achieve during the regulatory period, so that a percentage X might be set for them too.

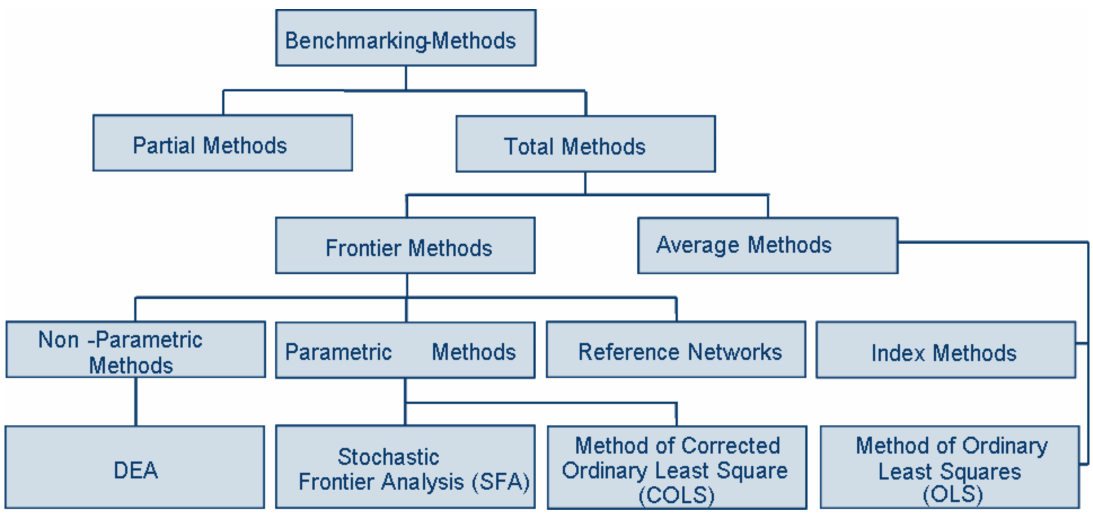

Figure 5 *Classification of Benchmarking Methods*

Benchmarking can also usefully be applied to service quality. Quality standards such as the number of customer complaints per 1,000 customers can usefully be benchmarked. Quality incentive schemes which penalise/reward utilities for poor/good performance can be based on the relative performance of a regulated company. To the extent that regulation seeks to improve quality standards, this could be relevant and becomes matter for further analysis.

There are two general approaches to benchmarking which have been used by regulators in real-world cases. One approach is to set the X factor equal to the average total factor productivity (TFP) growth rate of the relevant industry (electricity, water etc.). This has been used, for instance, in the regulation of individual US telecoms utilities where X was set equal to the rate of productivity growth of the US telecoms sector as a whole. This uses the average TFP growth rate of all US telecoms utilities as the comparator for a given regulated utility. Alternatively, more general TFP benchmarks could be used such as the (weighted-average) productivity growth rate of all network-based sectors. These measures have the effect of completely de-linking the setting of X from the behaviour of individual regulated utilities, and of giving the set of regulated companies the same X factor and are compatible with the yardstick competition model.

However, in many European counties, like Norway, Austria and the UK, regulators have tended towards cost-linked benchmarking which uses other electricity companies as the comparators against which actual company costs are compared. In the linked approach, the X factor for each individual company is set as a function of its relative performance to other companies. X factors are therefore set with reference to the measured inefficiency of the given company vis-à-vis a sample of companies from the same sector and from comparable backgrounds.

We now examine a number of different methodologies for economic benchmarking. The methodologies differ in the calculation of the relevant benchmark and, consequently, in their data requirements. As a general principle, we shall seek to employ several methodologies for benchmarking. This reflects the fact that there is as yet no consensus on the best methodology to use, and that each of the methodologies has unique advantages as well as limitations.

3.2.1 'Partial', or uni-dimensional, benchmarking methods

Uni-dimensional measures of performance (or performance indicators), such as GWh distributed per employee or minutes lost per customer, are the simplest measures of performance that can be compared. Clearly these can provide important indicative information on relative performance which give rise to the suggestion that a given company could improve its performance in a particular or "easy" way, e.g. by reducing staff numbers. Such measures appear in annual reports of companies and are commonly used by market analysts because they are seemingly easy to calculate and interpret. However, they are unsatisfactory because electricity national networks, regional networks and licensed supply companies are engaged in multi-input, multi-output processes. A company that performs well on one measure may do badly on another, while one company may do reasonably well on all measures, but not be the most efficient on any. How are such companies to be compared? Due weights ought to be given to the performance of the regulated company over a number of inputs and outputs. We discuss this in the following text.

3.2.2 Multi-dimensional benchmarking methods (efficiency analysis)

Economic efficiency analysis is a concept much used in the industrial organisation literature and has its origins in the microeconomic theory of production and cost. The applied use of comparative efficiency analysis is just a by-product of the typical microeconomic problem of the measurement of efficient cost and production levels, and of the separation between different types of inefficiency in production. Multi-dimensional efficiency analysis benchmarking methods exist to tackle the issue of multi-input, multi-output production utilities.

3.2.2.1 Average Efficiency Methods

Total Factor Productivity (TFP) Indices

Total factor productivity (TFP) measures may be used to provide unlinked benchmarks of performance for companies. Total factor productivity growth rates can be calculated by using the Tornqvist index: this is measured as the ratio of the output index divided by the input index. Thus, TFP = (output index)/(input index), with both the input and output indices being given by the weighted averages of all inputs and outputs used for production, respectively (see for more information Appendix 1). Weights are equal to the inputs' and outputs' cost/revenue shares in total cost/revenue, respectively. The index can also be taken in logarithmic form.

The Tornqvist TFP index can be compared between sectors over a long period of time. The growth rate of this index – for either with respect to the whole economy or some subset of it - can then be set as the benchmark for the electricity industry. The simplest form of CPI-X would set X equal to the actual or lagged value of the chosen TFP index's rate of growth. This measure would have the advantage of being simple to calculate and implement, and of achieving the medium term goal of an equal value of X for all regulated companies in the same jurisdiction. The disadvantage of this measure is that it does not take into account any company-specific information on initial cost inefficiency, and hence the scope for cost reduction. An extremely inefficient company would by definition be able to easily outperform any benchmark, while an efficient company with little scope for cost reduction would find it difficult to cut costs further at the rate imposed by the general TFP growth. This reflects the fact that TFP growth is the sum of technical progress and the reduction in relative inefficiency.

The Malmquist TFP is able to decompose the TFP growth into relative efficiency change (firms getting closer to the frontier) and technical progress (frontier shift) (see for more information Appendix 3). The Malmquist TFP index measures the TFP change between two data points by calculating the ratio of the distances of each data point relative to a common technology.

Ordinary Least Squares (OLS)

Regression analysis of existing company costs and output levels has been extensively used by regulators to establish productivity differentials between samples of local monopolies. The methodology involves estimating a cost or production equation of the type:

$Y = f(\underline{x}) + g(\underline{z}) + errors$, *or*

$C = f(\underline{w}, \underline{y}) + g(\underline{z}) + errors$,

where Y is a function of a vector of inputs ($\underline{x}$) and environmental variables ($\underline{z}$) if production is measured, or C is a dual function of a vector of input prices and outputs ($\underline{w}$, $\underline{y}$), and again of environmental variables ("cost drivers"). Statistical errors can then be either of the one- or two-component type.

The equation is estimated by ordinary least squares (OLS) using all of the data on the comparator set of companies. The estimated equation represents an "averaged" output/cost function, or "central tendency". For a given company *i*, its actual outputs, input prices and environmental factors can be plugged into the estimated equation to generate an estimated (fitted) cost. This can be compared to the actual cost as a vertical distance in traditional OLS fashion. The vertical distance in either cost/cost driver or output/input space will then be a simple measure of the efficiency of individual companies. Thus for the relatively inefficient utilities, this vertical distance represents the costs that could be saved if this company moved on to the regression (relatively efficient) frontier. These regression differentials can then be used to set the differences in the X factors between companies.

The drawback of the OLS method is that it relies heavily on the specification of the function: including different variables, or changing the shape of the function by trying with, for instance, non-linear variations on the theme will change the estimates and hence the calculated cost differentials and inefficiency scores. Some guidance in the specification of functions are available from standard statistical tests, but even generalised functional forms such as the "translog" or "Diewert" specifications are far from perfect for the sake of real-world applicability.

3.2.2.2 Frontier Efficiency Methods

This section outlines a number of commonly used efficiency measures and discusses how they may be calculated relative to an efficient technology, which is generally represented by some frontier function. Frontiers have been estimated by applied economists and econometricians using many different techniques over the past forty years. If we ignore for a moment the simple averaged estimation that Ordinary Least Squares (OLS) provides, the three principal methods[8] which lead to some degree of 'best practice' – and not simple central-tendency - outcomes are the following:

- Corrected Ordinary Least Squares (COLS)
- Stochastic Frontier Estimation (SFE), also known in the regulatory practice as Stochastic Frontier Analysis (SFA), and
- Data Envelopment Analysis (DEA), which is the focus of much practical regulatory work in the field of electric utilities.

These methodologies involve econometric and mathematical programming methods. The discussion in this Section provides a brief introduction to modern efficiency measurement based on such techniques[9].

Corrected Ordinary Least Squares (COLS)

The previously mentioned methodology, OLS, is in fact very closely related to the methodology of *Corrected Ordinary Least Squares* (COLS). In this methodology, efficiencies are calculated on a 0 to 1 range, with 1 being 100% efficient.

A cost/production equation is estimated exactly as in the regression analysis above, and this is converted into an efficiency score by taking the largest negative/positive residual (respectively) and subtracting this figure from - or using it as a ratio normaliser for - all of the differentials. The process generates a series of corrected cost/output differentials (residuals) whereby the most efficient company has a differential of 0 (or a ratio of 1) and the least efficient company has the largest positive differential (or the smallest fractional score).

In COLS, the inefficiency score for an individual company E is calculated as the ratio of efficient costs to actual/inefficient costs (or inefficient output to efficient output) and this represents the proportionate reduction in costs (or the proportionate increase in outputs in case of output maximisation model), which should be achieved if company E were to shift on to the regression frontier and thus became best-practice (point D). Notice that, by construction, the COLS best-practice frontier does only contain one 100% efficient company.

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[8] See M.G. Pollitt (1995).

[9] A more detailed treatment is provided by Fare, Grosskopf, and Lovell (1985, 1994), and Fried, Lovell, and Schmidt (1993). With special respect to Data Envelopment Analysis, an interesting overview of DEA is in Seiford and Thrall (1990), whereas the two basic DEA models being developed in the late Seventies and early Eighties - to which most applied papers still refer - are those by Charnes, Cooper, and Rhodes (1978) for constant returns to scale (CRS) DEA, and by Banker, Charnes, and Cooper (1982, 1984) for variable returns to scale (VRS) DEA. A new perspective on DEA in principal-agent theory terms has been provided by Bogetoft (1994) and in more recent applied papers written by this author, sometimes in co-operation with Per Agrell, on applied regulatory topics in Scandinavia.

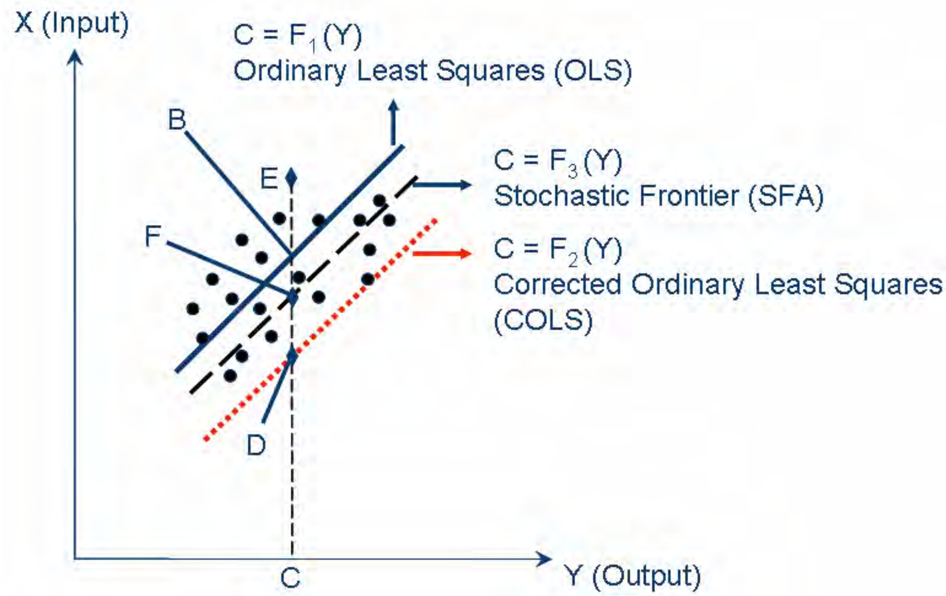

Figure 6 *Statistical (regression-based) methodologies, their generated frontiers, and the data scatter.*

COLS is the most straightforward of a set of benchmarking methods collectively known as "frontier techniques". These techniques are based on the implicit or explicit estimation of the cost function of an efficient company, which thus provides the benchmark against which the actual performance of the regulated utility can be measured. The COLS method requires the specification of the form of the efficient cost function and relies heavily on the position of the single most efficient company to determine the relative efficiencies of all of the other companies. It makes no allowance for the possibility of measurement error or chance factors (such as an unusually low cost year) in the calculation of efficiency estimates (i.e., it assumes that there is no stochastic error as separate from genuine inefficiency, which is hardly tenable in the presence of stochastic shocks in cross-sectional samples).

Stochastic Frontier Analysis (SFA)

Deterministic frontier analyses have been most used in the sixties and early seventies[10]. The need for separating efficiency errors - i.e., those due to the company erroneously shifting within its production possibilities set - from purely random noise led theoretical researchers in production econometrics to devise a brand-new framework which was capable of dealing with 'efficiency errors' (one-sided), as separated from either noise or imperfect information[11].

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[10] Nerlove (1963), in Zellner (1968); Christensen and Greene (1976).

[11] Hebden (1983); McElroy (1987).

SFA attempts to estimate an efficient cost frontier that does incorporate the possibility of measurement error or chance factors in the estimation of the efficient frontier. The relationship between the COLS and SFA frontiers are illustrated in Figure 6, where C = f3(Y) might represent the (imaginary) SFA frontier given by the data which generated C = f2(Y) as a COLS frontier. In estimating this frontier, a company such as E has had some of its apparently lower costs attributed to a negative stochastic shock to costs, and hence it now lies above the COLS efficient frontier (compare E's position with the COLS scenario which is point D with its efficiency position with the SFA scenario which is F). So SFA first allows the adjustment of individual company costs for stochastic factors, and then calculates efficiency scores in a way that is broadly similar to that under COLS. The efficiency scores are usually (much) higher than under the COLS method precisely because even the most efficient company under COLS will be assumed, under SFA, to be subject to some negative stochastic factor affecting its actual costs and/or outputs.

While SFA incorporates stochastic factors alongside genuine inefficiency effects, it still requires the specification of a functional form for the efficient frontier. Unfortunately, as compared with OLS and COLS it further requires the specification of a probability density function according to which the stochastic errors are distributed.

The original specification of SFA[12] involved a production function for cross-sectional analysis, featuring an error term which had two components, the first one to account for random effects (a traditional, two-sided disturbance term), with the second one accounting for technical inefficiency (a one-sided error). This model can be expressed in the following form:

$$Y_i = X_i\beta + (v_i + u_i), \qquad i = 1,\ldots,N,$$

where :

Y_i = production (possibly logged) of the i - th firm;

X_i = a $k \times 1$ vector of (transformations of the) input quantities of the i - th firm;

β = a vector of unknown parameters;

v, u = two separate random variables.

The two-sided random error (v) is assumed to be identically and independently distributed as a normal, with zero mean and constant variance. In particular, such a traditional two-sided random disturbance is independent of u, which is assumed to be a non-positive random variable accounting for technical inefficiency in production. The 'efficiency error' u is often assumed to have a truncated normal, half-normal, gamma, or exponential distribution[13]. If a cost function is used instead of a production relationship, the one-sided error will be non-

[12] The stochastic frontier production function was independently proposed by Aigner, Lovell, and Schmidt (1977), and Meeusen and van den Broeck (1977).

[13] See also Greene (1990).

negative, thus reflecting efficiency errors leading the utility to shift above its cost-minimising contour.

The original stochastic frontier specification has been used in a vast number of empirical applications over the past two decades. The above, standard specification has also been altered and extended in a number of ways. These extensions include the specification of more general distributional assumptions for the efficiency error (*u*), such as the two-parameter gamma distribution; the consideration of panel data and time-varying technical efficiencies; the extension of the methodology to cost functions and also to the estimation of equation systems[14].

Going back to the one-sided or 'efficiency' error, it must be emphasised that the (in)efficiency component cannot be observed directly. In fact, it must be inferred from the composite error[15]:

$$\varepsilon_i = v_i + u_i .$$

Cost efficiency in SFA is simply given by:[16]

$$EFF_i = \exp(u_i) \lesseqgtr 1,$$

depending on the main relationship being either a production or a cost function, respectively. Notice that, if the dependent variable is not expressed in natural logs, the above expression will not be valid. The following one should be used instead:

$$EFF_i(linear) = \frac{X_i\beta + u_i}{X_i\beta} \begin{cases} \in (0,1] \text{ for a stochastic production frontier;} \\ \in [1,+\infty) \text{ for a stochastic total cost frontier.} \end{cases}$$ [17]

Schmidt and Sickles (1984) identified three shortcomings of the cross-sectional estimation of stochastic frontiers: first, the assumption that company-specific inefficiency is uncorrelated with the explanatory variables can be violated; secondly, the error term may not always be normally distributed; finally, the estimate of *u*, the efficiency error, may not be consistent. Panel data estimation of stochastic frontier models, which is able to overcome the above

[14] A number of comprehensive reviews of this literature are available, such as those proposed by Forsund, Lovell, and Schmidt (1980), Schmidt (1986), Bauer (1990), and Greene (1993b).

[15] Jondrow, Lovell, Materov, and Schmidt (1982) derived an explicit form that decomposes the total error term. The interested reader is referred to their paper and also to Battese and Coelli (1988, pg. 392-393).

[16] This is computed by software packages in order to construct efficiency scores for every firm in the sample, being used to build up a final 'efficiency ranking' of all observed units.

[17] Jondrow et al. (1982) also derived similar expressions for exponentially distributed efficiency errors, whereas Stevenson (1980) did the same for the truncated model.

limitations, is reviewed and implemented by Burns and Weyman-Jones (1994a)[18]. The estimation of both cross-sectional and panel data stochastic frontier models is carried out by an econometric technique known as Maximum Likelihood Estimation (MLE).

Battese and Coelli (1992) proposed a stochastic frontier production function for (unbalanced) 'panel' data which has company-specific efficiency effects being distributed as truncated normal random variables. Such utility-specific efficiency errors are also permitted to vary systematically with time. A cost-function alternative to more traditional production functions is also provided by the authors. There are obviously a large number of model choices that could be considered for any particular application. For example, a half-normal probability distribution for the (in)efficiency effects might be assumed, instead of the more general truncated normal distribution. Furthermore, provided that panel data is available, one could assume either time-invariant or time-varying inefficiencies. One could even revert to deterministic OLS estimation if she believes that the *u* term is not significant, and should then be removed from the model altogether.

Traditionally, a number of empirical studies[19] have estimated stochastic frontiers and predicted company-level efficiencies by using these estimated functions. Then, they regressed predicted efficiency scores on environmental variables (including ownership types) in an attempt to identify some of the reasons for differences in predicted efficiency scores among companies in a given industry. This has long been recognised as a useful exercise. Lovell (1993, pg. 53), with reference to both stochastic frontier and DEA analyses, points out that "[...] It is worth thinking hard about what variables are inputs and outputs that belong in the first stage [i.e., either production/cost estimation or first-stage DEA], and what variables are explanatory variables that belong in the second stage. This must be done on a case-by-case basis, of course. The only general guideline I have to offer is that variables under the control of the decision-maker during the time period under consideration belong in the first stage. Variables over which the decision-maker has no control during the time period under consideration belong in the second stage. Candidates for second-stage variables include quasi-fixed variables, site-specific characteristics, socio-economic and demographic characteristics, the weather, and so on". The author also discusses the possibility of estimating efficiency scores by limited-dependent variables techniques (e.g., Tobit) because of the censoring problem resulting from the 0/1 scale.

However, as Coelli (1996a) observes, the two-stage estimation procedure has also been long recognised as one that is inconsistent in its implicit assumption regarding the independence of the inefficiency effects (the *u*'s) in the two estimation stages. The two-stage

[18] Battese and Coelli (1988) provided a panel data counterpart to the above reported cross-sectional decomposition of the error term.

[19] e.g., see Pitt and Lee (1981).

estimation procedure is unlikely to provide estimates which are as efficient as those that could be obtained by using a single-stage estimation procedure[20].

Data Envelopment Analysis (DEA)

Theoretical Premises on Production Frontier Microeconomics

DEA is not connected to the methodologies explained above. Such methodologies are in fact based on econometric techniques, whereas DEA is based on linear programming. Being somewhat easier to understand and apply in practice, DEA is quite popular with regulators but is not devoid of failures. We will describe this technique, its pluses and minuses, and its applications in what follows.

Let us illustrated the DEA productivity-computation ideas by using a simple example involving companies which utilise two inputs (to make up the input vector, **X**) to produce a single output (**Y**), under the assumption of constant returns to scale (CRS)[21]. Knowledge of the unit isoquant of the fully efficient company[22], represented by SS' in Figure 7 permits the measurement of technical efficiency. If a given company uses quantities of inputs, defined by point P, to produce a unit of output, technical inefficiency for that company will be represented by the distance QP, i.e. the amount by which all inputs could be proportionally reduced without a reduction in output. This is usually expressed by the ratio QP/OP, which represents the percentage by which all inputs could be reduced. The technical efficiency level (TE) of a company is most commonly measured by the ratio:

$$TE_i = OQ/OP$$

which is equal to one minus QP/OP. This ratio will take a value between zero and one, and hence provides an indicator of the degree of technical (in)efficiency of the company. A value of one indicates that the company is fully technically efficient. For example, point Q is technically efficient because it lies on the efficient unit isoquant.

---

[20] This issue was addressed by Kumbhakar, Ghosh, and McGuckin (1991), and Reifschneider and Stevenson (1991), who proposed stochastic frontier models in which the inefficiency effects (u) are expressed as an explicit function of a vector of utility-specific variables plus a random error.

[21] The CRS assumption simplifies the analysis by allowing the use of unit isoquants. Furthermore, Farrell also discussed the extension of his method so as to accommodate more than two inputs, multiple outputs, and non-constant returns to scale.

[22] The production function of the fully efficient firm is not known in practice, and thus must be estimated from observations on a sample of firms in the industry concerned. In this paper, DEA is meant to estimate the efficient production, or 'best-practice', frontier.

If the input price ratio, represented by the line AA' in Figure 7, is also known, allocative efficiency may also be calculated. The allocative efficiency level (AE) of the company[23] operating at point P is defined by the ratio:

AE_i = OR/OQ,

since the distance RQ represents the reduction in production costs that would occur if production were to take place at the allocatively (and technically) efficient point Q', instead of the technically efficient, but allocatively inefficient, point Q[24].

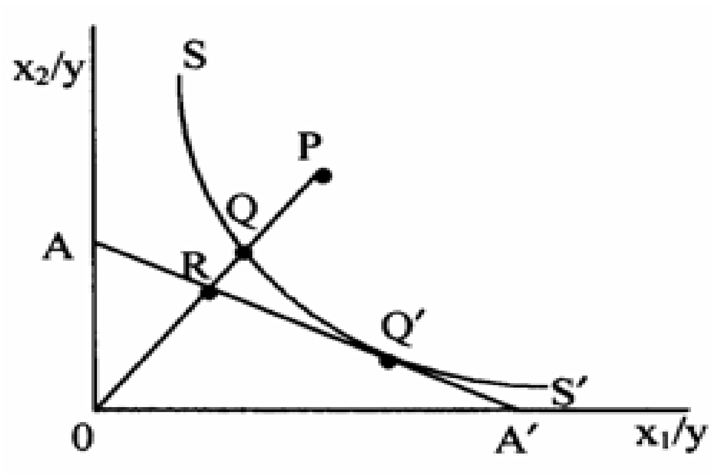

Figure 7 *Technical and input-allocative inefficiencies.*

To sum up, the total economic efficiency level (EE) for the company will be defined as

EE_i = OR/OP,

where the distance RP can also be interpreted in terms of a cost reduction. Notice that the product of technical and allocative efficiency provides the overall economic efficiency level (multiplicatively separable), which is also known as 'Farrell efficiency':

$$TE_i \cdot AE_i = \frac{OQ}{OP} \cdot \frac{OR}{OQ} = \frac{OR}{OP} \equiv EE_i.$$

[23] More generally, data points are for 'decision-making units' (DMUs), which can also be different branches of a single company.

[24] One could illustrate this by drawing two isocost lines through Q and Q'. Irrespective of the slope of these two parallel lines (which is determined by the input price ratio, or relative price), the ratio RQ/OQ would represent the percentage reduction in costs associated with moving from Q to Q'.

A mathematical formulation of DEA

DEA can be described as an extension of simple input to output ratio analysis, rigorously generalized to handle multiple inputs and multiple outputs. DEA does not require any functional specification of the efficiency frontier, but instead bases this frontier on actual observed performance. In DEA, the frontier is formed from the observed performance of the companies in the analysed sample, as determined by the relationships between inputs and outputs. The companies that form the efficiency frontier use the minimum quantity of inputs to produce the same quantity of outputs.

Calculating efficiency scores using DEA boils down to solving a series of linear problems.

Consider a sample consisting of N companies, each of whom using K inputs to produce M outputs. The vector (x_i) represents the inputs used by company (i) to produce a set of outputs (y_i). Suppose now that (u) is an Mx1 vector of output weights and (v) a Kx1 vector of input weights. In that case, the measure of efficiency is given by:

$$\frac{u^T y_i}{v^T x_i}.$$

That is, efficiency is defined as the weighted ratio of outputs to inputs. By definition, efficiency is a scalar ranging between zero and one, which respectively denote no (0) and full (1) efficiency. Efficiency for company (i) can now be calculated by finding appropriate values for (*u*) and (*v*). This requires the maximization of all efficiency ratios under the constraint that these are equal to, or less than, one. This can be written down as the following optimisation problem:

$$\begin{aligned}
&\max_{u,v} \frac{u^T y_i}{v^T x_i} \\
&\textit{subject to}: \\
&\frac{u^T y_i}{v^T x_i} \le 1,\ j = 1 \ldots N \\
&u, v \ge 0.
\end{aligned}$$

Solving this problem, however, leads to an infinite number of solutions. This drawback can be overcome by adding an additional constraint:

$$\begin{aligned}
&\max_{u,v} u^T y_i \\
&\textit{subject to}: \\
&v^T x_i = 1 \\
&u^T y_j - v^T x_j \le 0,\ j = 1 \ldots N \\
&u, v \ge 0.
\end{aligned}$$

Using duality theory, this can then be written down in the most "popular" form for the DEA problem, which is as follows:

$$
\begin{aligned}
&\min_{\theta,\lambda} \theta \\
&\textit{subject to}: \\
&-y_i + Y\lambda \geq 0 \\
&\theta x_i - X\lambda \geq 0 \\
&\lambda \geq 0.
\end{aligned}
$$

In this linear problem format, matrices X and Y represent, respectively, the input and output data space - which consists of the individual input and output vectors x_i and y_i for all N companies. The optimisation problem needs to be run for each company and results in the efficiency score θ (which is a scalar). An intuitive approach to the DEA problem is that, for each company, one tries to determine the distance to a multi-dimensional frontier that is given by the envelopment of all efficient input and output combinations. The efficiency score of an individual company is then measured as the distance between its own position and that of its "shadow", or projected, efficient point (a linear combination of real observations) on the best-practice frontier.

DEA has the advantage that multi input/output models can be used while data requirements are kept limited. In addition, the deterministic approach of DEA is advantageous from a regulatory point of view because no precise functional form (or no form at all, apart from convexity restrictions) relating inputs to outputs needs postulating by the regulator[25].

Constant versus Variable Return to Scales

An assumption of the method described above is that size of a company does not matter. By taking the ratios of inputs and outputs the frontier is normalized with respect to size of the company. The implicit assumption is that small companies and large companies can be compared with each other without taking account for possible efficiency differences resulting from scale effects. In the original DEA model developed by firstly introduced by Charnes, Cooper and Rhodes in 1978, constant returns to scale were assumed. This model consequently is referred to as the CCR or the CRS model.

Not taking scale differences into account in the benchmark analysis has however some drawbacks. Some of the inefficiency may arise from scale effects over which the company has no influence on. This constraint can for example be technical such as a network company situated on an island or by government policy (e.g. national champion, merger policy) A practical problem is that CRS increases the risk that data errors in the inputs and

[25] Some structure is sometimes imposed even on DEA, but not in its simplest, deterministic form – which is the one most used in the applied regulatory realm.

output are amplified when small companies are on the frontier. Then, relatively small errors in the data can have substantially absolute impact for companies who are not located on the frontier.

Such effects can (partly) be overcome under the so-called VRS (Variable Returns to Scale) model – or also known as the BCC model, named after Banker, Charnes and Cooper who first introduced it in 1984. Under the VRS model, the scale of the company is taken into consideration when performing the comparisons. An example of the VRS frontier is shown in Figure 8. The frontier is now not determined by a single company, but is the envelope of companies which are efficient taking their scale into account. Mathematically this is done by constraining the size of λ to unity. The linear problem then has the following form:

$$
\begin{aligned}
&\min_{\theta,\lambda} \theta \\
&st \\
&-y_i + \mathrm{Y}\lambda \geq 0 \\
&\theta x_i - \mathrm{X}\lambda \geq 0 \\
&\sum \lambda = 1 \\
&\lambda \geq 0
\end{aligned}
$$

The effect of constraining λ makes sure that a company is compared to peers of similar scale. The difference between the VRS and the CRS score is a measure for scale inefficiency. In this way the overall inefficiency can be decomposed into scale inefficiency and pure technical inefficiency. The disadvantage of a VRS model is that data requirements are higher because the discriminative power of the model decreases – to establish the frontier, more companies are needed under VRS than under CRS. The choice whether to adopt a CRS or a VRS model is also driven the degree of flexibility allowed to the network service providers to change their size. In case that mergers and de-mergers are allowed by the national legislation the regulators may deem the CRS as the more appropriate model as it may adopt the view that customers should not be allowed to pay for inefficiencies arising from improper scale selection.

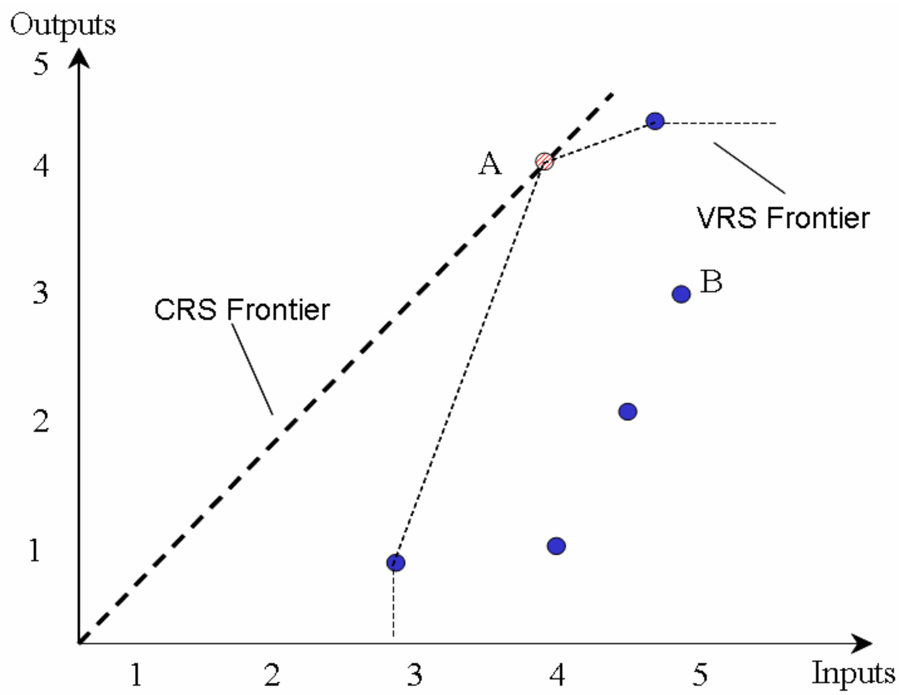

Figure 8 *Constant Versus Variable Return to Scales*

Accounting for the operating environment in DEA

The technical efficiency score produced by DEA indicates how far an organisation lies from the efficient frontier, and the proportionate reduction in inputs that would be required to reach the frontier. In a static (cross-sectional) context DEA does not, however, show whether it is possible for a company to move towards the frontier when moving up to the frontier is an impossible task because of the presence of exogenous constraints entering the optimisation problem.

In practice, a company's ability to move to the efficient frontier may be constrained because of factors associated with the environment in which it operates, which cannot be influenced by managers (at least, not in the short run). This could include public-choice constraints that require units to use a certain amount or type of input, or – more generally - characteristics of the service area such as population density, demographic mix, regional GDP, socio-economic indicators, different landscape and weather conditions, and the like.

Various approaches can be used to account for the influence of the characteristics of the units' operating environment. These include:

- Model specification: the DEA technique compares those units in the sample that use broadly similar input-to-input and output-to-output mixes. For example, units with relatively similar levels of cost (input) per kWh, per network length, and per inhabitant and similar levels of physical infrastructure per inhabitant are directly compared with each other in DEA. This goes some way to separating, for instance, the more rural from the more urban units in the sample. The rural units, for example, will be compared to other units in the sample with relatively similar input ratios;

- Explicit consideration of external variables in the DEA computations: environmental factors that are accounted for, to some extent (if not completely), by the model specification used in DEA are inserted as extra constraints in the linear optimisation problem. Alternatively, they can be viewed as second-stage variables within a subsequent, econometric framework catering for the statistical explanation of "pure" DEA efficiency scores by means of "environmental" explanatory factors. To a large extent therefore, model specification - combined with a large and diverse sample - ensures that the companies are compared fairly with other companies in the sample that convert similar mixes of inputs into similar mixes of outputs. Specifying second-stage variables in DEA or, alternatively, examining environmental factors in a second-stage econometric regression is by no means a perfect solution to the exogenous factors problem. Nonetheless, cross-checking the two alternatives and controlling for likely inter-correlation of core variables and environmental ones is a step forward in trying to understand the actual drivers of relative inefficiency; and
- Dividing (splitting) the sample: the sample can be sub-divided on the basis of common operating environmental characteristics. For example, the sample could be split up into a number of sub-samples on the basis of those companies with a similar topography, and efficiency comparisons are made between the companies within each group. Potential problems with this approach are that the sample size might be reduced to such an extent that the results are no longer as useful, and that a considerable amount of information is lost about how companies operate in different environments. In addition, a relatively large sample of companies is always needed, otherwise the inclusion of more variables in DEA can saturate the model, thus giving rise to an excessive number of "efficient-by-default" companies, and artificially inflating the efficiency scores as a consequence.

A Comparison of DEA and Stochastic Frontier

In order for methodological cross-checking to be fully understood, the following differences between DEA and SFA must be kept in mind:

Specification of Functional Form

The DEA technique does not require the specification of a functional form for the production function. Such flexible functional forms as the translog definitely improve the situation, but are not able to clarify how different components of efficiency might be separated within SFA.

Stochastic frontier methods are generally unable to effectively distinguish between input-allocative and technical efficiency and encounters serious problems with input-allocative efficiency computations[26].

Stochastic Properties

The DEA technique is non-stochastic[27] and does not take errors (random noise, measurement error) into consideration, unlike the SFA technique. Empirical work always involves some degree of measurement error, data handling errors, stochastic shocks, *et similia*. On the other hand, the ability of SFA to handle errors only comes at the expense of either the imposition of a functional form for the errors themselves[28], or the use of panel data[29].

Variable Choice

DEA scores are heavily affected by specification and variable selection errors. On the contrary, SFA frontiers give rise to standard errors and *t*-values for each of the parameters (e.g., in a translog total cost function). It is also true that sophisticated sensitivity analysis of DEA scores might be a possible solution to this problem, but it would be indeed complex and time-consuming.

DEA allows easy extension to multiple outputs in a production frontier context, and can also accommodate non-discretionary variables into the analysis in a direct way. On the contrary, SFA may only be extended to multiple outputs within a cost frontier setting. However, an excessive number of outputs (or inputs) in DEA will rapidly give rise to an excessive number of best-practice units. This may result in a tighter constraint on the number of inputs/outputs which can be inserted in DEA - as opposed to SFA - without saturating the model[30].

Computational Power

From a computational point of view, differences between DEA and SFA are now negligible, as a consequence of modern computing power. SFA involves econometric estimation of either a production or a cost function (plus share equations, if feasible), whereas DEA

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[26] Battese and Coelli's (1995) 'Technical Efficiency Effects' model, for instance, sorts out the problem by simply assuming that allocative efficiency is ex ante full (AE ≡ 1), thus ascribing all deviations from best-practice efficiency to technical effects (apart from random noise).

[27] Some researchers have tried to develop a stochastic version of DEA (see Land, Lovell, and Thore, 1988, and Lovell, 1993), but those models are by no means complete, and require massive data information regarding expected values, variance-covariance matrices, probability levels, and so on. Stochastic DEA would solve the main methodological problem with Data Envelopment Analysis, and is therefore worth investigating to a larger extent in the future.

[28] See Jondrow, Lovell, Materov, and Schmidt (1982), and Greene (1993b).

[29] See Burns and Weyman-Jones (1994a).

[30] On the 'parsimony' requirement of DEA, see Ferrier and Lovell (1990).

implies a separate linear program for each DMU in the sample. The most recent DEA software is capable of accommodating thousands of simultaneous linear problems automatically, so that computer programming skills are no more essential.

Reference Networks (Engineering Models)

Traditional economic benchmarking tools such as Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), and Corrected Ordinary Least Square (COLS) all share the common limitation that, in order to perform a meaningful comparison, a relatively large data sample is required. Furthermore, these tools are often used on the assumption of a certain model specification i.e. definition of the input and output factors. The results of the benchmarking analysis can be strongly driven by the choice of input and output specification. At the same time, verification of the benchmarking model is typically possible to a limited extent. This particularly applies to DEA, which is generally the preferred regulatory benchmarking methodology in practice.

Network models have a mixed engineering and economic/mathematical background and differ from the more traditional economic benchmarking techniques in two main ways. Firstly, network models are based on the comparison of the company's performance against that of an artificially constructed "optimal" company. This optimal company (the benchmark) is thus not a real existing one but rather follows from the rules and procedures embedded within the network model tool. This contrasts with the traditional benchmarking approach where the optimal company is derived through an empirical analysis of real companies. Network models thus effectively bypass the need for a benchmarking sample and can in principle be applied to the case of a single company.

The second factor that sets network models apart from traditional models is the fact that network models are based on an engineering approach. Traditional benchmarking techniques are based on economic or econometric/programming techniques. Here, the specification of the input and output factors is based on what the analyst thinks should be appropriate. For doing so, relatively little information or expertise in the actual network planning and operation business is required. Traditional techniques thus adopt a relatively high-level view of the network business. This makes traditional models more prone to critique as one may feel that they may not fully capture the existing complexities surrounding the network business. Network models on the other hand develop the optimal network on the basis of an engineering cost function. That is, they replicate consider the different variables and decision variables relevant to the network planning and replicate the process of constructing and operating the network.

Generally speaking, two classes of network models can be identified. Firstly, network reference models, which do not make use of standardised optimisation algorithms but instead are developed and applied on a more or less case-by-case basis. These models aim to derive the optimal costs for a given existing network by considering potential savings in the area of operations, maintenance, losses, etc. In dong so, a high degree of subjectivity i.e. expert opinion is involved. Secondly, there are network optimisation models, which construct an optimal network based on information regarding demand. This is done using a standardised algorithm and thus does not require any subjective assumptions other than in the modelling procedure itself.

Network reference models, which are for example applied in Chile, construct an optimal network based on an individual engineering analysis of the company's costs, demand conditions, etc. These network models do not make use of automated calculation routines but rather follow from individual assessments of the company's performance in different areas. The starting point is the existing network structure as built by the company. Then, the scope for possible cost reductions are identified and translated into a benchmark cost level for each geographical network zones and network function (e.g. maintenance, losses control). The analysis is typically conducted by independent consultants and involves the input by company engineers and accountants. Carrying out the analysis can be lengthy and may well exceed one year.[31]

The second class of network models consists of network optimisation models. In contrast with network reference models, these models make use of a standardised algorithm in order to arrive at the cost and performance criteria for the optimal network. This procedure makes use of different data such as the geographical location and the size of the loads, electricity consumption, connections to other networks, etc. Using this information, algorithms are applied to determine the optimal location of transformers, routing of lines or cables, select the most appropriate size and type of equipment, etc.

Network models can play an important role in the further improvement of traditional benchmarking models such as DEA. By combining the advantages of both types of models,

[31] In Chile, network models are an important aspect of the regulatory process. Here, an ideal company is constructed based on the actual demand and the expected load growth. Starting from the existing grid configuration and assets, an optimisation is performed of the maintenance, operations, and management of the company. The analysis by the consultants takes into account fixed costs such as administration, invoicing and user service expenses as well as variable costs, which include network losses, investments, operational costs, and maintenance costs. In order to maintain comparability between companies and company departments, four network zones (high density, urban, semi rural and rural) are identified where each zone represents an area of homogeneous technical and economic conditions. The network model determines the cost that would be incurred by an efficient company supplying electricity to a mixture of zones corresponding to the actual company. Quality is not considered in the optimisation process. Both the Chilean regulator and the distribution companies perform optimisation studies using different consultants. The cost corresponding to an efficient company is defined as the weighted average of the regulator's estimation of the optimal cost and that of the company where the weights are set at 2/3 and 1/3 respectively. The results of these studies form the basis for determining the company's income. The models used for the analysis are however not public and the technical details of the calculation of the cost incurred by the model company are not disclosed due to the highly detailed nature of the analysis. What is clear however is that there is no common optimisation methodology but rather, different methodologies are employed by respectively the regulator and the companies (as well as amongst companies). This is reflected in large differences between the regulator's and the companies' estimations of optimal cost levels.

more effective and valid benchmarking analysis can be conducted. At the one hand, traditional models provide the possibility to derive information in a relatively simple and labour-extensive manner. Network models on the other hand are based on generally acceptable engineering assumptions and therefore ideal to crosscheck the validity of a given model specification. Joint application of the two techniques combined the strengths of both and indeed can be considered the new trend in the electricity network benchmarking. text

3.2.3 Considerations on Quality of Supply Incentives and Benchmarking

Quality is typically not considered by regulators when conducting benchmarking analysis. This is an important limitation as excluding quality ignores the fact that costs are not only related to the level of outputs, but also to the quality level at which these outputs are supplied. For a given level of outputs, higher quality will generally lead to higher costs. Thus, in a cost-only benchmarking model, firms who are providing high quality may potentially be incorrectly classified as less efficient. Ideally, therefore, the efficiency score (and consequently the X factor) should reflect potential for improvements in the cost as well as in the quality sense.

Two main approaches may be identified for incorporating quality into the benchmarking analysis. In the first approach, quality is defined in terms of a technical output factor (technical model). The second approach models quality in terms of a cost input (social cost or sotex model). The latter approach is in principle preferable to the former one when applying integrated price-quality benchmarking.

3.2.3.1 Quality as an output factor: Technical Model

Under the technical model specification, quality would in principle need to be defined as an output factor. That is, if inputs increase (e.g. more investments are made) then quality output levels would consequently also improve. Thus, modelling quality as an output factor takes into account the fact that higher quality is associated with higher costs. Providing higher quality at given costs would then lead to a higher efficiency score. Generally, however, quality is defined and measured in terms of its inverse, for example by the number or duration of interruptions. In that case, the efficiency score would need to be increased at lower levels of inverse quality (e.g. fewer or shorter interruptions). A technical model therefore needs to specify inverse quality as an input factor: Higher levels of inverse quality would then – ceteris paribus – lead to a lower efficiency score.

Specification of quality in terms of a technical output (or more specifically, inverse quality as a technical input factor) is one step into the direction of integrated price-quality benchmarking. However, there are some problems involved in this approach. Under DEA for example, a firm is automatically assigned an efficiency score of one in case it scores best on a given input/output combination, irrespective of how it performs in terms of other input/output combinations. Thus, if a certain firm scores very high in the quality sense, it could be considered fully efficient even if it would perform very badly in the cost sense. Conversely, a firm that performs very well in the cost sense but provides a very low quality would potentially also be classified as efficient.

The technical model may provide firms with an adverse incentive to specialise in either high quality or low costs. Specialisation increases the efficiency score although this does not necessarily mean that the resulting trade-off between cost and quality is socially desirable.

3.2.3.2 Quality as a Cost Input: 'Sotex' Model

Ideally, the efficiency score should reflect the company's potential for arriving at a more desirable level of total social costs. This can be achieved by modelling quality in terms of a cost input and, more specifically, by defining social costs (sotex) as the input factor of the DEA model. Sotex includes both the firm's private costs (opex and capex) and the interruption costs incurred by consumers. Having defined sotex as the input factor, the firm's efficiency score will be higher if the firm manages to make a more optimal trade-off between costs and quality i.e. to reduce the level of sotex. On the one side, providing a higher quality level will decrease the level of interruption costs experienced by consumers. On the other side, the firm's own costs will increase. At a given quality level, the sum of these separate elements will be minimised – this will then reflect the optimal quality level. Operating closer to this optimum drives down sotex and potentially increases the efficiency score.

The efficiency score represents the difference between the actual and the desired sotex level – as disclosed by the benchmarking analysis. A score lower than one implies that the company could potentially decrease its sotex level. This can be done in two ways. Firstly, the company could keep productivity fixed and change the level of quality into the direction of the optimum. If initially the company provides a quality lower than the optimum, it will increase quality. This leads to an increase in network costs but also to an even larger decrease in interruption costs. Similarly, if quality is initially higher than the optimum, a decrease in quality will increase interruption costs but this will be eclipsed by the corresponding decrease in network costs. In both cases, the quality change leads to a net reduction in the level of sotex.

The second way through which the company can reduce social costs is by becoming more productive. Keeping quality fixed, the company can increase productivity levels and therefore provide the same level of quality but at lower costs. Alternatively, the company can produce more units of quality at the same cost. In contrast with quality, productivity maximisation is always a desirable objective as this leads to a reduction in total social costs. A change in quality on the other hand is only desirable if the firm steers into the direction of the optimum quality level.

In short, reducing sotex can be achieved by providing a quality level that is closer to the optimum or by operating at a more productive level (or by a combination of these two).

4 The Process of X factor Computation

4.1 Computation Principles

4.1.1 Controllability of Costs

The price-cap mechanism aims to provide incentives for better productivity performance. Underlying this objective is the assumption that the company is actually able to control its level of costs. This may not be necessarily true for all types of costs. There may be some costs that are beyond the company's control and therefore, it would not be reasonable to expect any productivity improvements in this area. Such non-controllable costs may include items such as taxes, regulatory contributions, fees for connection to other networks (e.g. transmission networks or neighbouring distributors), and costs resulting from force majeure events (e.g. natural disasters).

The incentives would only need to apply to controllable cost items, non-controllable costs would be allowed to be passed through to consumers on the basis of actual costs. The definition of non-controllable costs is not free from ambiguity, however. It may be that some costs are considered non-controllable while in reality, these costs can be (partially) influenced by the company. Take for example network losses. These costs are driven by two factors namely the amount of physical losses (measured in kWh) and the price paid per unit of kWh of losses. Both these factors are to a certain extent controllable by the company. For example, operating at higher voltage levels, increasing network capacity, or using better equipment can reduce physical losses. Although there may be some investments involved in doing so, the fact remains that these losses can (to some extent) be influenced by the company. Similarly, the price paid for network losses may be reduced by working out better electricity purchase deals to fuel these losses. If the regulator would consider network losses fully non-controllable, the company would have no incentive to reduce these losses nor to purchase the electricity efficiently i.e. at lowest price possible. Furthermore, some adverse incentives may arise. The company could for example deliberately purchase losses at a higher price from affiliated electricity selling companies.

With respect to controllable costs, the company can increase productivity through its own efforts. Controllable costs thus can be regulated on the basis of any of the price-cap strategies described in Chapter 1. Generally, regulators distinguish between two types of controllable costs namely costs that are controllable in the short-term (operational expenditures – opex), and costs that are controllable only in the longer term (investments or capital expenditures – capex).[32] Opex typically includes the costs of personnel, maintenance, and overhead costs such as buildings and office rentals, administration, transportation, etc. The company could adjust its level of opex in a relatively short period. For example, it could immediately reduce its maintenance activities, dispose of personnel, or attract additional staff.

4.1.2 Capex Measurement

Capex has a long-term nature and is controllable only in the longer run; in the short run, capex can be considered fixed. These costs typically relate to investments for extending network capacity as well as for upgrading quality.

The measurement of capex is traditionally problematic. Investments are typically undertaken at different time intervals and tend to considerably vary in size. Investment lumpiness might be characterised by substantial fluctuations in cash spending from year to year, which could lead to misleading results in the benchmarking. Averaging capex spending for a number of years can partially smooth out the figures, but will not completely account for differences, in particular when companies turn out to be at different stages of their investment cycles.

A superior alternative is to represent capex as an estimate of annual capital consumption. According to this approach, a stream of annual investment figures is converted into a stock of assets (on which a return is earned), and into a stream of annual depreciation figures. In this case, annual capital consumption is measured as the sum of the capital cost's components: return on assets and depreciation. This method replicates the canonical regulatory accounting scheme used to establish allowed revenues, and paves the way for total cost benchmarking of a top-down type using either econometric or linear programming techniques.[33]

The general idea is that, during some predetermined period (the depreciation period) the company earns back the cost that it paid for the investment and the cost of capital necessary to fund the investment. In its simplest form, the annual depreciation would be equal to the purchase price of the asset, divided by the depreciation period of that asset. The second capex component is the return on the investment; this is generally defined as an annual rate-of-return on the un-depreciated portion of the investment. The rate-of-return is typically set by the regulator based on an assessment of the company's costs of capital. Companies have two sources to finance their investments. Firstly, they can attract debt and secondly, they attract equity. For these finance sources, the company should pay interest and a

[32] The distinction between short-term and long-term costs, generally denoted as labour and capital, is the usual one in economic theory.

[33] However, network age and investment cycles are not properly reflected in this model and may well distort the credibility of results. This issue can be addressed by using annuities instead of depreciation plus return in the annual measurement of capital consumption.

dividend respectively. These costs combined (weighted through an efficient gearing ratio) determine the company's costs of capital.[34]

4.1.3 Demand Forecast

The price-cap mechanism aims to provide incentives for better productivity performance.

In addition to productivity, both opex and capex levels will be driven by demand. Ceteris paribus, if demand increases, then the absolute level of costs will also increase. At the same time, in the face of scale economies, the increase in costs will be less than proportional to the increase in demand.

In the setting of the X factor, the regulator may in principle need to determine productivity improvement potential as a function of demand growth. There are, however, some problems involved here. If the regulator sets the X factor at the start of the regulatory period (e.g. as under isolated or related caps), a forecast of future demand will need to be made. Given that such forecasts would be imperfect, there will be an error in the regulator's determination of the X factor. Forecast errors can be corrected at the end of the regulatory period by recalculating the X factor using actual demand figures. Alternatively, the regulator may correct for demand forecast errors in the intermediate i.e. from year to year within the regulatory period.

Although the effects of uncertainty in demand can be corrected for in the longer term, they may cause risks to both companies and consumers in the shorter term. The form of the price-cap scheme largely determines the way in which these risks are allocated between company and consumers. That is, the way in which differences between forecasted and actual demand are treated. For example, the regulator could choose to completely ignore such differences. This particular form of price-cap is known as the pure price-cap. In this case, assuming economies of scale, the company would bear all risks associated with forecast errors. If demand growth is lower than expected, the company's revenues will suffer and its profitability may be jeopardised. Similarly, the company could earn additional profits in case that actual demand is higher than forecasted.

4.1.4 Smoothing of Revenue Streams

The X factor can be defined in terms of a gradual change in the price towards a level that corresponds to the efficient level of costs. Note that the X factor can either be positive or negative. If the X factor is positive, this implies a gradual reduction in price levels. The X

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[34] This is usually expressed in terms of the Weighted Average Costs of Capital (WACC) which is the weighted average of debt and equity costs Cost of debt usually follows from an analysis of market interest rates. Cost of equity are more difficult to measure and typically involve the use of the so-called Capital Asset Pricing Model (CAPM).

factor can however also be negative. Initially, if prices were too low to fully recover the company's costs, it may be necessary to increase these prices, even if there is potential for efficiency improvement. That is, prices may be expected to drop due to expected efficiency gains but this reduction may be eclipsed by the required price increase in order to bring prices up to reasonable levels. The net effects thus may be a negative X factor implying an increase in prices during the regulatory period.

An X factor, whether positive or negative, suggests a smooth gliding path from the existing towards the efficiently deemed price level. However, consideration needs to be given to the fact that costs levels are driven by demand, which may vary from year to year. Also, given that the price includes investments and non-controllable costs, prices are not likely to follow a smooth course over time but will rather fluctuate from year to year. For reasons of price stability however, such fluctuations are generally not desirable.

To achieve a gradual change in prices, the X factor is typically calculated in such a way that the net present value of the company's revenues and the allowed costs during the regulatory period is equal to zero.[35] Starting from the initial price p_0, the X factor is then set as follows:

$$\sum_t \left(\frac{1}{(1+r)^t} \cdot (1-X)^t \cdot p_0 \cdot q_\tau \right) = \sum_t \left(\frac{1}{(1+r)^t} \cdot (opex_t + ror \cdot RAB_t + D_t + others_t \right)$$

Here, t is the year, r stands for the discount rate in the present value calculations, X is the X factor, p_0 is the price in the initial year, q_τ is the corresponding volume for year τ.[36] The total revenue in present value terms generated by the company is given by the left-hand side of the formula and is set equal to the present value of the allowed costs. These costs include opex, a rate-of-return (*ror*) on the Regulatory Asset Base (RAB) and an allowance for depreciation (*D*) as well for other costs that are considered non-controllable. The RAB reflects the net value of the investments undertaken by the company; it is adjusted annually to take into consideration new investments (*Inv*) as well as depreciation (*Dep*). This can be represented in the following way:[37]

$$RAB_{t+1} = RAB_t + Inv_t - Dep_t$$

Simply stated, the essence of the price-cap system comes down to determining an appropriate level for each cost component during each year of the regulatory period. This is then in turn reflected in the X factor. Given that the parameters p_0, q, and *ror* as well as the

[35] In this case the X factor is a solution of the equation that sets the difference of both net present values at zero. Thus the X factor incorporates two functions: implied efficiency increase in the capex and opex streams and the smoothing through discounting formula.

[36] The variables t and τ do not necessarily refer to the same year. The choice of τ in relation to t is an aspect of the form of the PCR control and determines the way risks resulting from volume forecast errors are allocated between firms and consumers. As mentioned earlier, this aspect will not be considered further.

[37] In practice the RAB would also need to incorporate disposals as well as capital contributions. Furthermore, some regulators also include an allowance for the costs of working capital in the definition of the RAB.

initial RAB are known, the X factor would then simply be calculated by identifying an appropriate level for the annual OPEX, the RAB, and the allowed depreciations.[38] This effectively boils down to making two decisions: Determining the efficient opex level and determining the efficient level of investments that should be annually allowed to enter the RAB. For this purpose, the regulator could apply any of the price-cap strategies discussed in Chapter 1.

Given that there are two cost categories to be regulated, two basic approaches can be identified. Firstly, the regulator could separately assess OPEX and CAPEX (investments). Essentially, the price-cap can then be thought to consist of two components or building blocks namely an allowance for OPEX and an allowance for CAPEX (which would consist of depreciation plus a rate-of-return on the RAB). This approach is generally known as building blocks. The second approach is one where the regulator considers OPEX and CAPEX in an integrated fashion i.e. does not distinguish between them. Here, the sum of OPEX and CAPEX would be regulated on the basis of a single price-cap strategy. This approach is known as the total costs or TOTEX approach. The two approaches are now discussed in more detail.

4.1.5 Building Blocks Approach

Under the building blocks approach, the regulator needs to assess an efficient level of OPEX as well as an efficient level of CAPEX. In the determination of the efficient OPEX, regulators tend to make use of benchmarking analysis but there is typically no formal translation of efficiency scores into efficiency improvement targets; there is often some room for regulatory discretion in translating efficiency scores into the X factor. The general approach can therefore be classified as one of isolated caps. The notable exceptions are the Netherlands and Norway where the efficiency scores play a formal role in the determination of the X factor. In both jurisdictions however, the benchmarking applies to TOTEX and not to OPEX alone.

For investments, regulators typically set the allowed level on the basis of the company's own investment projections. The investments may be checked separately for efficiency but in many cases they are treated more or less as a pass-through item. At the start of the regulatory period, the company would be asked to provide the regulator with an overview of its intended investments during the next regulatory period. The regulator may then develop a view of which investments to include in the RAB or simply accept the company's projection as it is. Investments that have been allowed into the RAB will be completely recouped through the allowed depreciation while the company would also earn a rate-of-return over the un-depreciated portion of these investments. Related caps and yardstick competition

[38] The initial price p_0 would have been previously set by the regulator. Demand forecasts would be reflected in q while for the discount rate r, typically the allowed rate-of-return (*ror*) would be used.

strategies are, as far as known, not applied to CAPEX. The explanation for this is that there are some important problems attached to the benchmarking of CAPEX. This issue is explored in more detail elsewhere in the paper.

The “easy” allowance for CAPEX creates adverse incentives for the company to overstate its investment projections. The more investments are included in the RAB, the higher the capital base of the company will be and the higher will be the level of return that can be earned. This is an important problem as the company will be tempted to overstate investments in order to maximise future additions to the RAB and therefore boost profits. A related problem is that the company may also try to strategically allocate operational related expenditure under CAPEX if the regulatory strategy for the latter cost category is less strict. This removes some of the OPEX from the incentive regime while it also leads the company to appear more efficient in OPEX terms and obtain a higher efficiency score. Furthermore, by capitalising OPEX, the company can further inflate its RAB and consequently earn higher returns.

Once the X factor has been set, the company would in principle be free to decide its own investment level. At the end of the regulatory period, it may well be that the company invested less than originally planned. This difference would, as the company may claim, be due to higher productivity and therefore, in the spirit of price-cap regulation, should be awarded to the company. Although this line of reasoning is in principle correct, it may be that (part of) the resulting savings are in fact driven by inflated investment projections or deliberate under-investments rather than genuine productivity improvements.

To mitigate this problem, an investment target could be imposed. If actual investments turn out to be lower than the target, then prices are accordingly adjusted downwards. Similarly, no ex post allowances would be provided for investments in excess of the target. Alternatively, the regulator could impose a band of desired investment levels with a minimum and maximum target; investments exceeding this band would not or would only be partially allowed into the RAB[39]. This approach however comes at the cost of weaker incentives on the CAPEX front. The regulator would (partially) claw back cost savings irrespective whether these are the result of strategic under-investing or due to genuine productivity improvements. This makes it unattractive for the company to achieve any productivity improvements in the area of CAPEX as there would not be any financial rewards attached to this anyhow.

4.1.6 Total Cost or ‘TOTEX’ Approach

Under the TOEX approach, the regulator does not differentiate between OPEX and CAPEX anymore but sets the X factor on the basis on the sum of these i.e. on the basis of total costs

[39] Alternatively the allowed return can be lower, for the investments that exceed the planned level.

(TOTEX). In practical terms, this means that the regulator does not need to consider investment projections by the company but instead performs a benchmarking analysis of actually incurred levels of TOTEX. The resulting efficiency scores then form the basis for setting future allowed TOTEX levels. The efficiency incentives of the TOTEX approach come from the fact that each regulatory period, the X factor is set on the basis of performance achieved in previous years. If the company manages to increase productivity, its efficiency score will be higher in future periods and consequently its X factor will be lower. This is an important difference from the building blocks approach where problems of assessing CAPEX projections hinder the determination of efficient levels of CAPEX.

Under the TOTEX approach, the problem of investment assessments is effectively bypassed. Furthermore, as the TOTEX approach does not distinguish between OPEX and CAPEX, the company (as well as society) may also achieve efficiency gains by trading-off better between labour and capital inputs. Under the TOTEX approach, the regulator does not need to develop a view whether a given investment proposal should be allowed or not. Rather, the regulator considers the actual total costs (including investments) incurred by the utility and sets the X factor based on an analysis of these costs.

4.1.7 Efficiency Convergence Speed

The X factor prescribes the rate of change in the company's prices, reflecting the expected transition from the existing price level towards the price level that is deemed more appropriate by the regulator. With respect to the setting of the X factor, two issues should be taken into account. First, the regulator needs to decide whether the existing price level will serve as the starting point for the regulatory formula of whether an adjustment (so-called P0 adjustment) in this initial price is required. Second, the regulator could choose to set a so-called cap (maximum or minimum) to the level of the X factor. We now discuss these two choices in more detail.

4.1.7.1 P_0 Adjustment

Generally, the regulator sets the X factor for the full regulatory period i.e. to be applicable during each year of that period. This X factor then reflects the annual change in the company's initial price level P_0 such that, at the end of the regulatory period, the price is at the desired level. An alternative approach is to first adjust the company's initial price, and then apply a X factor to this adjusted price. The P_0 adjustment would bring the regulated business's revenue into line with the estimated revenue requirement in the first year. The X factor is then applied with these adjusted prices as the new starting point. The regulator can set the X factor, given the P_0 adjustment, at a level that equates the NPV of forecast revenue over the regulatory period with the NPV of the allowed revenue requirements. The alternative approach is to determine the X factor exogenously and instead compute the P_0

on the basis of equating the NPV of forecast revenue over the regulatory period with the NPV of the allowed revenue requirements.

The advantage of a P_0 adjustment is that prices can be brought to more realistic levels at once, and after that, a relatively lenient X factor can be applied. Whether this approach is preferred or not will depend on what type of P_0 adjustment one is dealing with. If initial prices are initially lower than what should be the case, the P_0 adjustment will come in the form of a one-off increase in prices. Clearly, this can have significant political and social impact and for this reason, may be less preferred. Rather, the regulator could then choose for a more gradual increase in prices, basically spreading the P_0 adjustment over a couple of years.

In the case that prices are initially higher than what they should be, a downwards P_0 adjustment may look like an attractive option to the regulator. Large one-off adjustments (P_0 adjustments) quickly eliminate the inefficiencies at the beginning, and allow a low X factor in the remaining regulatory period. On the other hand, loading all the anticipated cost savings into the P_0 reduction gives a misleading picture of the scope for ongoing efficiency during the regulatory period as reflected in the lower X factor.

4.1.7.2 A Cap on the X factor

The X factor reflects, among others, the expected improvement in efficiency performance that the regulator considers to be possible for the regulated utility to achieve. This potential in efficiency improvement is revealed by the benchmarking analysis. For practical reasons, it may not be possible for the company to completely materialise the measured efficiency potential during the regulatory period. The company may need more time. For example, even if the company is initially overstaffed, contractual constraints may prevent a quick dismissal of personnel. This may take a number of years to accomplish (e.g. through natural outflows). Such factors would reasonably need to be taken into account by the regulator. This can be done by setting a cap on the X factor i.e. setting a maximum to the value that the X factor can take. This cap reflects the minimum level of improvement that the regulator considers realistic for the company to achieve.

Determining the level of the cap on the X factor depends on the actual situation that one is coping with. If the X factor is positive i.e. prices are due to be reduced, then it is in the company's best interest to have an as low as possible cap on the X factor. In contrast, if prices are expected to increase i.e. the X factor is negative, then the regulator could use a cap to protect customers against a too fast increase in price. In the Netherlands, where the X factor was positive, the regulator adopted a cap on the X factor of 8%. Similarly the Norwegian regulator limited the X factors at 4.5 % (max. individual X factors of 3.0 % for all companies have efficiency equal or less 70 % and general X factor of 1.5 %). In Romania, where the X factor was negative, the cap on the X factor was –18%.

4.1.7.3 Frontier Shift

Another issue that is also important to consider within the context of efficiency convergence speed, is the so-called frontier shift. The benchmarking analysis provides information on the scope for efficiency improvement of companies that are less efficient that the benchmark i.e. the best performing companies in the benchmarking sample. By definition, these benchmark companies will have an efficiency score of 100%. Notably, the efficiency score is relative and should be put in the context of the sample being considered. There are two reasons why a score of 100% may not necessarily apply to the benchmark companies.

First, the benchmarking analysis is naturally constrained by the choice of the sample. It may well be that there are other, more efficient companies out there which were not included in the sample. Thus, a company that turns out to be 100% efficient may not necessarily be truly fully efficient. Second, even if the benchmark company is truly 100% efficient, one should also take into consideration the dynamic character of efficiency. Over time, there will be technological progress that will be reflected in a further increase in absolute efficiency levels. This effect is known as “frontier shift” and should be taken into consideration when setting the X factor. In practice, many regulators tend to estimate rather than actually measure the frontier shift. Typically, a range between 1% and 2% is considered suitable for the frontier shift. This additional efficiency improvement requirement then comes on top of the already established X factor. This applies to both companies that are already fully efficient (the benchmarks) and companies that initially have scope for improvement up to the level of these benchmark companies.

4.2 Ensuring Data Quality

4.2.1 Data Collection Process

The availability of good data is crucial to any X factor computation exercise. If the underlying data used is wrong, so will be the X factor. It is of utmost importance that regulators assure the use of high-quality data, making sure that definitions are clear and uniform, and that the received data has been audited according to clear guidelines.

Data quality is particularly relevant in the case that the X factor is computed on the basis of a comparative analysis. In this case, the X factor of one company is set on the basis of its costs and performance relative to other companies. If data for one of these companies is wrong, this may potentially impact the X factor of the other companies. Clearly, such as linked approach makes the regulatory process more sensitive to any data errors. This also created an opportunity for companies to strategically influence the regulatory process (regulatory ‘gaming’), as each subsequent correction in the regulatory decisions would have reduced the overall credibility of the whole comparative exercise. Experience shows that such outcomes are indeed very realistic; an important example is the Netherlands where a series of corrections were applied to the X factor during the judicial review process.

Irrespective of how the information being collected is used, regulators should be free by means of legislation to ask regulated entities for information without any confidentiality barriers. That is, the regulator should be authorized to collect data from the companies even if this data is considered confidential. At the same time, the regulator should also take into account the confidential character of the data where applicable in disclosing information to the public.

For the purpose of price-setting, the following categories of data are typically required at the minimum. These data are collected for the base year of the regulatory period as well as forecasted for the full regulatory period:

- Annual accounts including profit & loss account, balance sheets, and cash flow statements
- Details on operational expenditures, classified by controllable and non-controllable costs
- Structured information on net asset values per asset category
- Structured information on depreciation costs per asset category
- Structured information on new investments per asset category
- Structured information on physical parameters including number of customers, energy consumption and demand, all of them per customer groups

4.2.2 Standardisation and Template Development

Regulators typically collect information from regulates using data transfer templates which come in the form of spreadsheets and accompanying documentation explaining the definitions and providing explanations. Also, it is useful for regulators to conduct data workshops where the data submitted by the companies is discussed and it is assured that data is consistent with the regulator's definitions and requirements. Such data workshops are in the interest of both the regulator and the companies. For the regulator, the use of correct and valid data assures that the regulatory outcome i.e. the X factor is computed correctly. For the companies, it is important that the data that feeds into the price-setting process is valid in order to avoid any unfair results or ex post adjustments of the X factor in the case that it turned out that underlying data had been incorrect.

An important data standardisation aspect in the context of benchmarking is the capex. When collecting data on the company's (forecasted) investments, there is an important problem that needs to be considered. This is related to the long-term nature of investments. Capex (depreciation and returns) are spread over a number of years and therefore, a snap-shot of a single year may provide a biased picture. As the example from Table 1 shows, the costs in a given year can be strongly influenced by the timing of investments. In this simple example, utilities A1 and B1 both invest an amount of 400. In the long run, both companies will face the same level of depreciation costs. However, the companies differ in their timing of the investments. Utility A1 invests primarily in the last year while for utility B1, most investments are conducted in the first year. As can be observed, the effect of this is that utility B1 has high depreciation costs in the early years and relatively low depreciation costs in the later years.[40] If the regulator would consider only a single year, say the second year, utility A1 would turn out to be very efficient as it would have much lower costs (50) compared to utility B1 (with costs of 88). The reverse would apply if the benchmarking analysis was conducted later in time e.g. in the last year.

Firm A1 (depreciates in 4 years)					
		Depreciation (mln. EUR) for investments in year:			Depreciation Costs (mln. EUR)
Year	Investment (mln. EUR)	1	2	3	
1	100	25			25
2	100	25	25		50
3	200	25	25	50	100
4		25	25	50	100
5			25	50	75
6				50	50
Total	400	100	100	200	400

Firm B1 (depreciates in 4 years)					
		Depreciation (mln. EUR) for investments in year:			Depreciation Costs (mln. EUR)
Year	Investment (mln. EUR)	1	2	3	
1	300	75			75
2	50	75	13		88
3	50	75	13	13	100
4		75	13	13	100
5			13	13	25
6				13	13
Total	400	300	50	50	400

Firm A2 (depreciates in 2 years)					
		Depreciation (mln. EUR) for investments in year:			Depreciation Costs (mln. EUR)
Year	Investment (mln. EUR)	1	2	3	
1	100	50			50
2	100	50	50		100
3	200		50	100	150
4				100	100
5					-
6					-
Total	400	100	100	200	400

Firm B2 (depreciates in 2 years)					
		Depreciation (mln. EUR) for investments in year:			Depreciation Costs (mln. EUR)
Year	Investment (mln. EUR)	1	2	3	
1	300	150			150
2	50	150	25		175
3	50		25	25	50
4				25	25
5					-
6					-
Total	400	300	50	50	400

Table 1: *Simplified example of the impact of different depreciation policies and investment timing. All utilities invest the same amount over a period of three years and use straight-line depreciation but differ in the timing of these investments and the choice of depreciation period. Although in the long run depreciation costs are the same, annual depreciation varies considerably.*

This example demonstrates the importance of considering multiple years in a totex benchmarking analysis. Multi-year analysis, however, makes the benchmarking analysis more data demanding and therefore less practical. Consideration should also be given to the fact that the analysis may be hampered as a result of different accounting conventions in the treatment of capital costs. Consider the above example once more.

Firms A1 and A2 (or B1 and B2) both have the same investment pattern, but use different depreciation periods. Because of this, their depreciation cost measured in the same year

[40] For simplicity, only depreciation costs are compared. Similar effects would also apply to returns.

tends to be different. Company A1, which uses a depreciation period of four years, has lower costs in the earlier years than utility A2 that uses a shorter period of two years. Conversely, in the later years, utility A1 still incurs depreciation costs while utility A2 has already depreciated all assets.

Although the examples provided here are very simplified, they illustrate the basic problem of how ignoring the long-term nature of investments can distort the analysis results. Even though in the long run utilities invest at similar levels, their costs would fluctuate from year to year, reflecting differences in investment timing and accounting policies. Including multiple years in the analysis could solve this issue, but would also make the analysis more data demanding and therefore less practical. This is particularly true if the companies considered in the analysis used different accounting conventions. Performing a backward calculation of book and depreciation values could eliminate monetary effects resulting from such differences.

4.2.3 Data Verification and Auditing

The data reported back to the regulator should be reliable and auditable. Verification of the accuracy of the data can take place in different ways. The simplest approach is to perform so-called sanity checks of the data by crosschecking the correlation between different types of data and checking for any unexpected or strange effects such as outliers or internal inconsistencies. This relatively simple instrument can sometimes be useful in spotting obvious data errors in particular when the regulator has the ability to crosscheck data across a number of companies. For example, when verifying the data on the number on electricity consumption, one could compare the average consumption per customer across the sample. If one utility shows a very high or very low consumption pattern compared to others, this may potentially be the result of a data error.

Analysis of correlation between different data variables is a very simple instrument that can be effective for spotting obvious data errors such as use of different indicators or units (e.g. GWh instead of MWh) and identifying outliers in the data sample. A more elaborate instrument is the auditing of the company's submitted data.

Sometimes, regulators require companies to have their data audited first by an independent auditor, before submitting these to the regulator. Data is then only accepted if this is accompanied by a signed declaration of the auditor, specifying that the data complies (or does not comply) with the requirements as set out by the regulator. As part of this process, it may also be necessary for the regulator to issue specific auditing instructions as part of the data request sent out to the companies.

An alternative approach towards auditing is that the regulator conducts its own audit (with the assistance of external auditors) of the company's data. This is a somewhat more intrusive instrument and should in principle be avoided. However, if there are serious concerns that the data submitted by the company is not correct and the company does not recognise this, audits could be conducted by or on behalf of the regulator. This can for example be the case when there is a conflict between the regulator and the company and the company rejects to cooperate in data submission. Clearly, the possibility to conduct audits or to require the utility to have their data inspected first by independent auditors depends on the authority of the regulator, as provided by law.

5 International Experience

This Section deals with a number of international regulatory experiences with the setting of the X factor, benchmarking, and other related issues.

5.1 Austria

5.1.1 Price Regulation

E-Control Ltd. the regulator for the Austrian energy industry was set up in compliance with new Energy Liberalisation Act and commissioned her work on 1st March 2001.

Network regulation in Austria started out as an annual cost review (including tariff approval) by the regulator during the period 2002-2005. In 2002/2003 the regulator started her first initiative to introduce incentive regulation. These efforts were criticised by the Austrian electricity industry and their association. However, during the following years they realised that that it would be better to replace the annual cost reviews and the following price cuts by a regulatory framework with fixed conditions over certain years. A regulatory period with incentive regulation provides the industry with a clear framework for cost reductions and efficiency improvements and enables them to keep possible efficiency gains. In 2005 E-Control and the Austrian electricity industry agreed on an incentive regulation model using price-caps for a four-year regulatory period and the following regulatory formula (here for 2006):

$$K_{2005} \cdot \left[(1 - KA) \cdot (1 + \Delta NPI_{2006})\right] \cdot (1 + k \cdot \Delta M_{2006}) + vNK_{2006} = \sum_{i=1}^{n} P_{2006,i} \cdot Q_{2004,i} + ME_{2006} + BKZ_{2004}$$

with

K_{2005} = costs as per 31.12.2005

KA = cost adjustment factor (X-factor)

ΔNPI_{2006} = annual inflation (calculated on the basis of specific network industry price index)

k = weight for the increase in transported energy

ΔM_{2006} = weighted increase in transported energy on a year-on-year basis (2004-2003)

vNK_{2006} = cost of the network level

$P_{2006,i}$ = use of system charge 2006 for tariff component i = 1,..., n

$Q_{2004,i}$ = transported energy for tariff component i = 1,...,n

ME_{2006} = revenues from metering

BKZ_{2004} = capital contributions 2004

In the following, we describe the benchmarking process used to compute the annual efficiency improvement for network operators (called Kostenanpassungsfaktor, cost adjustment factor).

5.1.2 Efficiency Analysis

The individual efficiency requirement contained in the formula is based on a DEA and MOLS[41] (modified ordinary least square) comparison of the distribution companies.

- DEA (data envelopment analysis with constant returns to scale)
- MOLS (modified ordinary least squares)

E-Control has chosen different **benchmarking methods** to avoid the drawbacks from using a single method as follows:

- In case of using deterministic methods (DEA or COLS) efficiency results might be too low since wrong data and noise are treated as inefficiency.
- Efficiency results might be too high when specific characteristics of an operator distort the results

E-Control invested significant efforts to specify the model. E-Control decided to use TOTEX (OPEX+CAPEX) as input factor in the benchmarking model. Using TOTEX has the advantage that the choice on using capex versus opex ist left with company. Moreover it avoids any undesirable bias in the cost recording, e.g. capitalizing opex in case capex is not rigorously benchmarked. E-Control used TOTEX numbers stemming the 2005 cost review adjusted by the cost for payment to higher voltage levels.

In the process of selection of output parameter in the benchmarking model, E-Control followed the following principles:

- small numbers of parameters
- environmental parameters should be exogenous, i.e. non-controllable by network operators
- the output should explain the company's cost

The data availability was the main hurdle for the benchmarking process. In the process of selecting the parameters, E-Control used a model network in order to investigate how these parameters affect network costs. The model network analysis has shown that there is no

[41] MOLS is an extension of the COLS model.

single parameter to explain the cost of the network operator. Especially, the load density (load/km^2) and connection density (number of connections/km^2) turn out to be significant in explaining non-controllable cost differences. Furthermore, the regulator managed to establish a functional relationship between connection density (number of connections/km^2) and network density (line length/km^2) for sub-areas of the areas served by the network operators.

$$\frac{l_j}{A_j} = \sqrt{\frac{N_{NA,j}}{A_j}}$$

with

l_j = line length in sub area j

A_j = area [km^2] of sub area j

$N_{NA,j}$ = number of connections in sub area j

The line length in every sub area of the network operator can then be calculated as:

$$l_j = A_j \cdot \sqrt{\frac{N_{NA,j}}{A_j}} = \sqrt{N_{NA,j} \cdot A_j}$$

This relationship is further used to calculate area-weighted connection numbers for different voltage levels used as output in the benchmarking model.

E-control decided to use three different benchmarking methods (DEA I, DEA II and MOLS). All of them take TOTEX as input factor but different output factors. The different output factors are:

DEA CRS (I)

- peak load middle-voltage/low-voltage
- peak load low-voltage
- weighted transformed area-weighted connections/area for HV-MV-LV

DEA CRS (II)

- peak load middle-voltage/low-voltage
- peak load low-voltage
- area-weighted connections/area for HV
- area-weighted connections/area for MV

- area-weighted connections/area for LV

MOLS

- peak load middle-voltage/low-voltage
- peak load low-voltage
- weighted transformed area-weighted connections/area for HV-MV-LV

The results of the different models are depicted in the following figures:

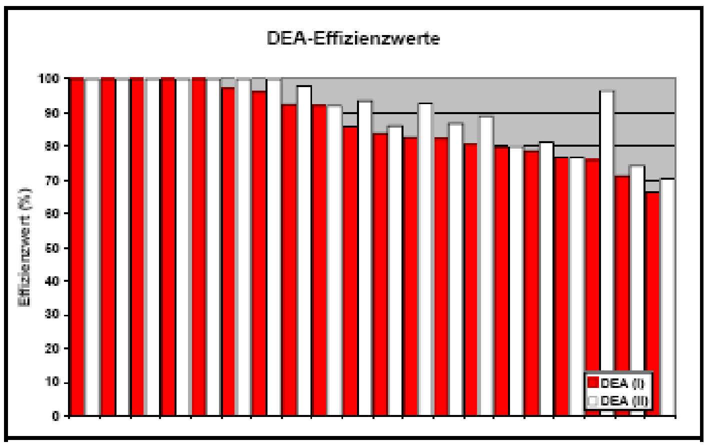

Figure 9: *DEA (I) and DEA (II) efficiency scores Austria*

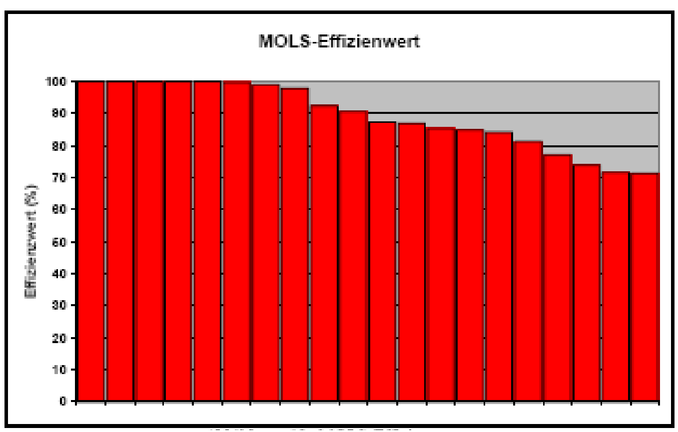

Figure 10: *MOLS efficiency scores in Austria*

The consolidated efficiency scores were calculated as follows:

$$ES_{2005} = DEA(I) \cdot 40\% + DEA(II) \cdot 20\% + MOLS \cdot 40\%$$

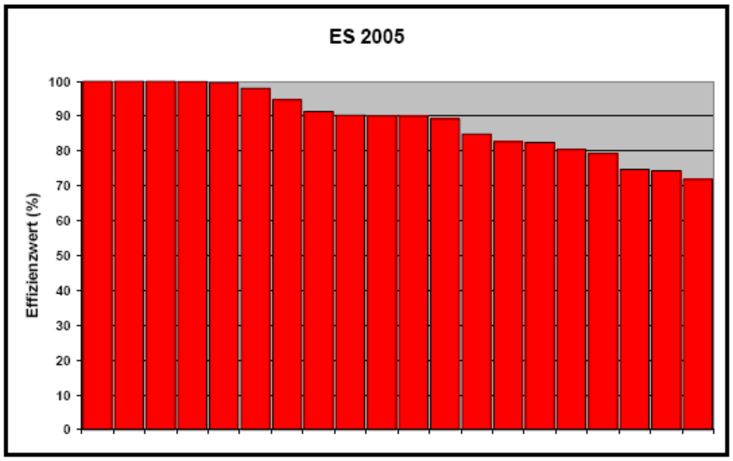

Figure 11: *Consolidated Efficiency Scores in Austria*

Using the consolidated efficiency scores, E-Control decided that the companies have to reach the efficiency frontier within eight years. In addition, E-Control fixed the maximal individual efficiency improvements with 3.5% per year. This implies that companies with individual efficiency scores below 74.76% are treated as their efficiency score were 74.76%.

Taking into account the annual frontier shift of 1.95%, this leads to the following annual efficiency improvements depending on the efficiency score:

Effizienzwert	KA
74,76%	5,45%
75%	5,41%
80%	4,65%
85%	3,92%
90%	3,23%
95%	2,58%
100%	1,95%

Table 2: *Total annual efficiency improvements (KA), Austria*

Figure 12 depicts the relation between the efficiency position (Effizienzwert) and the annual efficiency improvement (total X-factor, Kostenanpassungsfaktor).

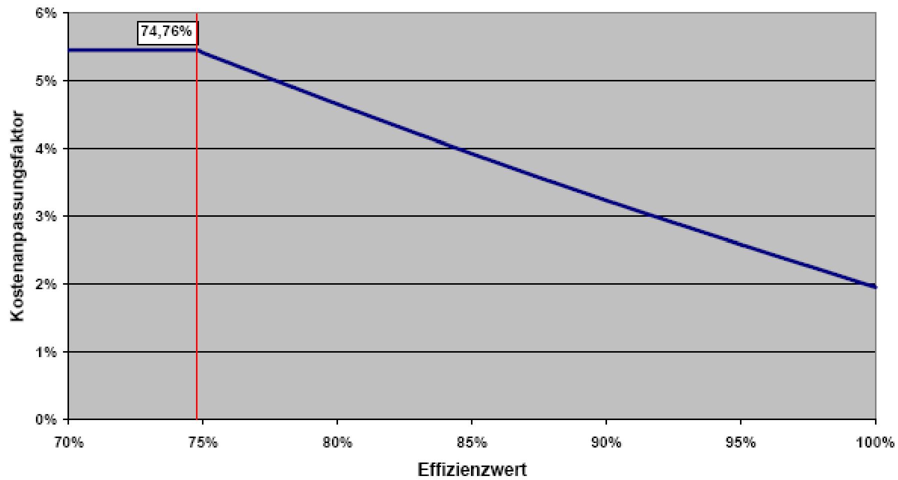

Figure 12: *Efficiency score and annual efficiency improvement in Austria*

5.2 Norway

5.2.1 Institutional Background

The Norwegian Water Resources and Energy Directorate (NVE) is the power industry regulator in Norway. The NVE is a directorate under the Ministry of Petroleum and Energy, with responsibility for managing the country's water and non-fossil energy resources. NVE's mandate is to ensure integrated and environmentally friendly management of the country's watercourses, to promote efficient energy markets and cost-effective energy systems, and to work towards the achievement of a more efficient use of energy. NVE is also responsible for reducing damage caused by floods and erosion along rivers and streams.

Network regulation in Norway started out as a rate-of-return scheme during the first price control period (1992-1996). However, the deficiencies resulting from this approach were soon recognised. The main issues turned out to be the inefficiency caused by guaranteed ex-post cost recovery and the weak incentives for productivity improvement. These considerations became the major reason leading to the replacement of the existing price control framework by a new incentive-based scheme in 1997. The current Norwegian regulatory system is an ex ante regulation method based on incentive regulation and revenue caps. Through efficiency incentives, NVE strives to encourage network owners to reduce costs and improve their efficiency. Under the new system, network owners are no longer guaranteed full cost recovery. By establishing a system whereby each network owner is allowed to receive pre-determined maximum revenue, the allowed profit will in principle coincide with the difference between allowed revenue and actual cost. Allowed revenue requirements should cover the networks' total cost: operation and maintenance; capital cost in the form of depreciation and return on capital invested; network losses; and profit taxes.

The regulatory model of Norway is based on revenue cap regulation, supplemented by benchmarking and profit-sharing mechanisms. Initial revenue caps were determined on the basis of regulatory accounts from 1994 and 1995. In 2002, NVE reset the price control for networks leaving the general logic of the revenue cap from the first regulatory period (1997–2001) untouched, however adjusting some of its components and pursuing the improvement of the regulatory cap's properties.

5.2.2 Price Regulation

Norway's revenue cap regulation for electricity transmission and distribution contains elements of different regulatory mechanisms. It consists of cost-plus regulation with a time lag, and benchmarking plays a crucial role in determining efficiency requirements. The revenue cap is determined by:

- The revenue cap from the preceding year, or primarily the cost in the first year of the regulation period, plus a standard return on capital for the same year;
- An expected efficiency improvement parameter, benchmarking-based; and
- An annual correction factor intended to provide an additional revenue as a function of pre-specified cost drivers.

The fact that the revenue cap is affected by these factors makes it possible for the grid owner to influence its return - not only by decreasing costs, but also by operating and maintaining the grid in such a way to ease the revenue cap.

The initial revenue values consist of the average operating and maintenance costs, depreciation, return[42] on invested capital (book value + 1% to allow for working capital), and average grid losses. The spot market price for power is used to assess the value of grid losses.

As said, in the first revenue cap period (1997-2001), the initial revenue caps were determined on the basis of grid company accounts from 1994 and 1995, according to the following formula:

$$RC_e = OPEX + DEP + r * RAB + L,$$

[42] NVE annually sets a reference interest rate based on the long-term risk-free interest rate plus a risk premium. The reference interest rate, r_n, is the basis for the return. The basis for the risk free interest rate is the ST4X index from the Oslo Stock Exchange. The risk premium is valued at 2%.

where RCe is the initial revenue cap determined by operating and maintenance costs (OPEX), depreciation (DEP), return on invested capital (r) on the asset base (RAB), and costs associated with energy losses (L). We also have:

L = LMWh · P, where:

LMWh denotes losses in MWh, and P is the average system price of energy during the whole year as gleaned from the NordPool spot market.

The dynamic time adjustment of the allowed revenue for the grids was based on the following formula:

$$RC_n = ((RC_{n-1} - RC_{n-1}) \cdot \left(\frac{CPI_n}{CPI_{n-1}}\right) + L_{MWh} \cdot P_n) \cdot (1 - X) \cdot \left(1 + \frac{\Delta E_{a,n}}{2}\right),$$

where:

- RC is the starting revenue cap (revenue requirement based on cost);
- CPI is the consumer price index;
- X is the efficiency requirement calculated at the beginning of the regulatory period by means of Data Envelopment Analysis (DEA);
- ΔE is the percentage increase in transported energy on a year-on-year basis; and
- n is the yearly time index.

The initial revenue is annually adjusted for inflation, the required efficiency increase, and by the term (1 + 0.5*ΔEa,n). The latter is designed to provide an additional revenue to the regulated grid companies intended to contribute towards the additional OPEX and CAPEX being incurred as a result of the increasing volume of transported energy. The anticipated efficiency improvement includes:

- An individual efficiency increase component – measured via DEA on inter-company comparisons; and
- A general efficiency increase component – imposed exogenously by NVE and reflecting the general technological improvement in the industry.

The current revenue cap scheme (2002-2006), with initial cost values taken from 1996-1999, is slightly different from the above description. Amongst other things, the last term in the formula was removed and replaced by a new term (Adjust) that adjusts for new investment, whereas the increase in transported energy was supplemented by a second driver, namely the relative increase in the number of buildings in each distribution area:

$$RC_n = ((OPEX + DEP + RAB \cdot r_n) \cdot \left(\frac{CPI_n}{CPI_{2000}}\right) + L_{MWh} \cdot P_n) \cdot (1 - X) \cdot + \text{Adjust}_n^i,$$

whereby the notation is as above. The Norwegian approach relies on the incentive to raise efficiency in the regulatory period while keeping any interim efficiency gains. The regulatory revenue re-setting is based on actual cost, including checks for any deviation between the prescribed revenue path and actual performance. In addition, the regulated grid providers are exposed to repeated benchmarking that is aimed to eliminate inefficiencies. In the current regulation period (ending 2006), the grid owner will not be able to influence the revenue cap directly. The revenue path is decoupled from actual cost via the application of the regulatory formula.

If we assumed that last year's cost level is the only basis for determining the revenue cap in the current period, we would impose no cost-reducing incentives on the regulatees. What NVE does instead is to benchmark the opening level of costs via DEA, and to impose an efficient totex level objective upon all regulated companies throughout the duration of the regulatory period.

There is an adjustment term in the revenue cap formula that exceeds the compensation implicit in the incentive to 'beat' the regulatory benchmarking-based cost target. On the assumption that new investment may be caused by an objective need resulting from changes in certain cost drivers, as well as being driven by safety and system security reasons, the investment revenue adjustment element in the revenue cap formula is intended to give the companies suitable compensation for expanding the grid. However, it is important that the adjustment term does not favour unnecessary and/or gold-plated new investment. In other words, the adjustment term should not incentivise the companies to influence their own revenues through uneconomic actions.

New investments involve capital costs such as depreciation and return on invested capital. The majority of such costs is already taken into account by updating the cost base for the revenue cap periodically. Cost recovery is, however, delayed in time because updates do not occur continuously. This entails that the net present value of the implied revenues is lower than what would be necessary to cover new capital cost incurred today. The purpose of the investment adjustment term in the revenue cap is to provide continuity in terms of investment recovery. In addition, new investment may have an impact on operation and maintenance cost, grid losses, and undelivered energy. Such (arguably positive) changes will not result in changed revenue caps for the utility until the next regulatory review, and must therefore be assessed when determining the level of the ongoing adjustment term. The share of capital costs associated with new investment that the adjustment term is supposed to cover depends on:

- the real timing of investments in relation to the four-year update timetable for totex
- the life time of the investments
- future inflation
- future efficiency requirements, and

- the return on capital (discount factor) for the grid owners.

NVE has calculated that between 64.8% and 94.5% of capital costs are already covered through the four-year totex revenue cap. The adjustment term shall therefore compensate for between 5.5% (100% minus 94.5%) and 35.2% (100% minus 64.8%) of the capital cost associated with the new investment.

5.2.3 Efficiency Analysis

The efficiency requirement contained in the formula (the X term) is based on a DEA comparison of all distribution companies (there are more than 150 in Norway, albeit now decreasing). As regards asset values, both book asset values and replacement asset values are considered as part of the total-cost DEA runs, which are then computed twice. Companies are given the 'benefit of the doubt' in that the most favourable DEA scores will be used for their revenue requirement calculations after comparing the efficiency score series from the two DEA runs. The relationship between the efficiency requirement and efficiency measurements based on DEA is softened in such a way that the individual cost improvement requirement will never exceed 3% annually for any distribution company reporting a DEA cost efficiency score of 70% or lower ('efficiency flooring'). Formally, the efficiency requirement target X is given by the formula:

$$X_D = 1 - (1 - (1 - EFF) \cdot 0.3824)^{1/4},$$

where EFF is the totex efficiency level for any given company as calculated via DEA, which is - as said - floored at 0.70 for all distribution companies with a reported 'raw' DEA cost efficiency score of less than such amount. For a grid owner with regulatory cost efficiency in the floored 70-100% interval then, the formula will mean that 38.24% of the individual inefficiency in the distribution grid must be recovered over the regulatory time span of 4 years. Any residual inefficiency will be carried forward to the following regulatory period.

5.3 United Kingdom

5.3.1 Institutional Background

The Gas and Electricity Markets Authority ("the Authority") is the formal name of the independent energy regulatory body in the UK[43]. Its executive office is known as Ofgem. Its duties and responsibilities include requirements to:

[43] Prior to the establishment of the Authority after 1997, regulation of the electricity market was carried out by OFFER (Office of Electricity Regulation) under an individual Director General.

- protect the interests of customers where appropriate by promoting competition
- secure that all reasonable demands for electricity are satisfied
- ensure that licence holders can finance their activities, and
- have regard to guidance from government on social and environmental matters.

5.3.2 Price Regulation

Following privatisation, a revenue yield control was applied in the United Kingdom. In 1995 the regulator moved towards a hybrid cap (mix between revenue and price cap) by varying the revenue formula, reducing the influence of volume to 50 percent and introducing customer numbers as the revenue driver for the remaining 50 percent. Although actual volumes distributed are used, customer numbers are set in advance, based on forecasts made at the start of the review period. As a performance incentive, a link is also drawn between allowed revenues and distribution system losses. This allows the distributors to retain a proportion of the benefit from any reduction in losses.

5.3.3 Efficiency Analysis

Ofgem (UK regulator for electricity and gas) has developed the regulatory framework of operating cost items for distribution companies, and has decided to benchmark OPEX only, whereas capital expenditure is subject to case-by-case overview and acceptance based upon engineering advice. The benchmarking data have been under continuous review with consultations from the Distribution Network Operators (hereafter, DNOs), and also using external specialist advice.

These costs were categorised as operating expenditure or OPEX[44] in the 2003 regulatory accounts using the methodology of Ofgem's Electricity Price Control Review 2003, hereafter 'DPCR', as follows:

Cost of Sales

- NGC transmission exit charges
- NTR costs for transmission and distribution interfacing (transformation, voltage scaling)
- other costs of sales

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[44] Some companies have grouped items together to form 'Administrative expenses' and 'Distribution costs'. The items that fall under this category can also vary from company to company.

Other operating costs

- employee wages and on-costs (consists of salaries, social security and pension costs)
- direct network costs (comprising materials, contractors and consumables)
- information technology
- insurance
- advertising and marketing
- professional services (comprises auditors' remuneration – for audit services, fees paid to group auditors for other services)
- bad debts/doubtful debt expense (net of recoveries)
- guaranteed standard of performance consumer compensation payments
- ex-gratia compensation payments
- health and safety
- network rates
- way leaves/servitudes
- Ofgem licence fee
- statutory depreciation expenses (net of customer contributions' amortisation)
- Other (details provided if > £0.5m)

For international benchmarking purposes, the UK's OPEX figures that have been derived from the 2003 regulatory accounts of the distribution companies should have the following costs deducted. These are depreciation, network rates and fees, and any energy purchasing costs.

Adjusted OPEX

After reviewing the questionnaires that Ofgem submitted to the DNOs requesting detailed information on historical and forecast data in regards to cost assessment, it became evident that the DNOs took different approaches or interpretations on various issues. This has resulted in Ofgem revising the categories of items that will be included in the future OPEX. In the Initial Proposals June 2004[45] document, for the next DPCR 2004, Ofgem has highlighted some changes and amendments of future categorisation of opex items.

[45] The final DPCR 2004 will be finalised once Ofgem has received and reviewed all responses and comments of all UK DNOs. The update DPCR 2004 paper was published in September 2004.

One of the main areas of difference across DNOs has been the allocation of costs to a category termed “fault costs” (i.e. the costs of repair and restoration after a fault or loss of power), and within that category to operating expenditure. Ofgem’s intention at the start of the current review was to assess fault costs separately, but to refer to the comment concerning variations of items and how different DNOs allocate categories of items, it finally became apparent to the regulator that some DNOs included indirect costs within reported fault costs. This led to significant inconsistencies across companies; therefore, Ofgem had decided to add all fault costs to operating costs before drawing comparisons across companies.

The other main normalisation adjustments have been the following:

- exclusion of network rates, depreciation, exit charges, non-trading rechargeables, other cost of sales, Ofgem licence fees, and costs associated with ‘de-minimis’ activities. These costs are either outside the price control or are the subject of separate assessments.
- exclusion of metering costs[46]
- removal of atypical and one-off costs
- removal of intra-company margins
- adding back projected average non-operational CAPEX[47] for some companies. Non operational CAPEX costs are included in an outsource contract and cannot readily be excluded, so comparable data is most easily provided by adding back the costs for those companies that incur such costs in-house. However, capital expenditure in any single year may not be representative (‘snapshot effect’), so the average forecast over the period 2005-2010 has been used.
- removal of intra-company margins (e.g. profit margins on recharges from related parties), as these are not genuine “costs”. Where the related party’s business is predominantly external to the group, the inclusion of an internal margin is being considered. But, for the purposes of this OPEX report, all margins have been excluded.
- removal of storm insurance costs for those companies that get insured against these as this storm costs in the UK are normally treated as an atypical item. (Insurance premiums relating to exceptional storm events have been removed as there are differing approaches adopted across DNOs - e.g. some of them self-insure.)
- pensions (actual costs removed and replaced by a standardised rate of 15% for comparison purposes).

[46] Presently undergoing liberalisation, therefore now separate from distribution in the UK.

[47] Capex - Capital expenditure.

- adjustments to the capitalization of overheads. UK DNOs have adopted different business models and overhead allocation methods. This has resulted in non-comparability of operating costs as some DNOs capitalize significantly different proportions of their overheads.
- adjustments for operating costs of 132kV in Scotland (due to a different definition of distribution line voltages in Scotland).
- adjustments for regional factors to take account of significant geographical, demographic and operational circumstances (including higher London/South East wage rates).
- other excluded items and adjustments, such as line rentals and congestion charges, adjustments for capitalization policies not compliant with Regulatory Accounting Guidelines (RAGs), revenue protection costs, R&D costs, fault boundary adjustments, and
- corporate costs (e.g. marketing etc.) that are not relevant to the operation of a DNO have been removed, whether they are allocated from parent companies or via a recharge from a related third party.

The exclusion of these costs does not, in most cases, represent a disallowance of costs. Some costs are outside the price control, others will be covered by separate allowances. Other adjustments may be a transfer to (or from) CAPEX. The only cost disallowed completely are inter and intra-company margins, but as explained above, where the related party's business is predominately external to the group, the inclusion of an internal margin is being considered by Ofgem.

The table below highlights the OPEX data before and after the Ofgem cost adjustments. DOPEX (Distribution OPEX) is the amount before any adjustments were made, and these are the figures used for the benchmark using actual data from the regulatory accounts[48]. CDOPEX (Controllable DOPEX) is with fault costs and losses deducted, and the final ACDOPEX (Adjusted Controllable OPEX)[49] is with all adjustments made. These figures illustrate the justification behind Ofgem's purpose of the cost adjustment, particularly the evaluation of OPEX with and without fault costs. The OPEX values after deducting fault costs (CDOPEX), result in a substantial difference, indicating efficiency and does not represent a true result when making evaluations and comparisons.

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[48] DOPEX for London Electricity, EPN Distribution, Northern Electric, Seeboard and Yorkshire Electricity has not yet been finalised between the companies and Ofgem.

[49] CDOPEX and ACDOPEX data is from Ofgem's Initial Proposals Document for DPCR 2004, 28th June 2004.

Distribution Network Operator	DOPEX (k€UR)	CDOPEX (k€UR)	ACDOPEX (k€UR)
London Electricity		93,750	98,250
Scottish Hydro	112,800	52,500	49,950
Southern Electric	222,000	89,850	84,750
Western Distribution Power - South West	143,700	80,100	76,650
Western Distribution Power - South Wales	132,750	57,000	53,850
EPN Distribution		132,900	126,600
East Midlands	189,300	94,500	91,050
Northern Electric		61,350	57,300
Midlands	237,600	102,300	95,850
United Utilities	150,450	103,950	97,650
Scottish Power/Manweb	156,450	80,550	77,100
Scottish Power Distribution	239,700	95,700	86,250
Seeboard Power Networks		103,950	99,150
Yorkshire Elec. Distribution		77,550	72,750

Table 3 *UK OPEX, before and after cost adjustments*

UK Distribution companies have been benchmarked according to these cost levels via a variant on Corrected Ordinary Least Squares (COLS). The regulator performs OLS on operating cost only, and then shifts the OLS line to a position which is an average of the third and fourth most efficient companies in the sample. In the previous distribution price review control, the OLS line had been shifted arbitrarily after pivoting it around the second-best company in the league and fixing the intercept (to approximate fixed operating cost) following consultation with engineering advisors. In the end, the full old OLS exercise had been de facto nullified. The current 3-to-4-shift method is perhaps a more defensible way of shifting out OLS, but it still does not amount to anything theoretically supported. It is just a modification of COLS dictated by purely practical considerations, which is – after all - what regulatory benchmarking is all about in any case.

5.4 Slovenia

5.4.1 Institutional Background

The Energy Agency of the RS (AERS) was established in January 2001 as an independent regulatory body. As regards the methodology of price regulation, price cap regulation (RPI – X) was chosen, which aims to give utilities incentives for efficient production and cost reduction. The Agency opted to set a price cap (tariff basket) that will not be changed during the regulatory period, thus giving some incentive for efficient production and stimulating cost reduction. The first regulatory period lasted three years (2003 – 2005).

The Energy Act adopted in 1999 requires separate accounting for energy-related activities which are carried out in addition to the other activities of the company. Also, separate accounting for each of the energy-related activities has to be provided. The separation of activities was carried out in order to avoid cross subsidization, increase transparency and enable easier monitoring of regulated costs. Electricity distribution companies thus have to maintain separate accounting for the following activities:

- the distribution of electricity (public service)
- the operation of the distribution network (public service)
- supply to tariff customers (public service)
- supply to eligible customers (market service), and
- other market-related activities.

One of the main tasks of AERS is to set prices for the use of electricity transmission and distribution networks. In so doing, AERS has to assess the eligibility of the costs and other elements of the price. The network charge is set in a way to cover the infrastructure network costs (including managing, operating, maintaining and development of the network) and the costs to make up for the technical losses in the network.

5.4.2 Price Control

The estimation of future revenue requirements for the regulated businesses in Slovenia will be achieved by aggregating three main “building blocks”: (1) efficient capital and operating expenditure, including cost of network losses; (2) non-controllable cost (e.g. purchase of transmission services and system service and payment for market and regulatory services); and (3) an efficiency carry-over element based on the previous regulatory review. As the regulatory price control will have been applied for the first time by the Agency, no efficiency carry-over from previous periods will be needed initially.

More specifically the allowed revenue for regulated network services (obtained from the network charges) is determined by considering the following categories:

- eligible operation and maintenance costs
- depreciation (AERS recognizes a 5% annual amortization or a 20-year lifetime for the new investments. Only 50% of the calculated depreciation is taken into account for the new investments in the first year)
- eligible costs to cover technical losses in the network
- return on assets (calculated on the basis of the average value of the regulatory assets base by considering a real before taxes WACC of 5.1%)
- deducting revenue from other regulated services.

Initially, the Energy Agency planned to use replacement costs for the establishment of the regulatory asset base (based on the assets re-evaluation exercise conducted in 2002 in Slovenia) and a real, risk-adjusted pre-tax rate of return to be set equal to the weighted average cost of capital (WACC) as determined by the Agency itself. Consequently, it turned out that the results of the asset re-evaluation exercise were not reliable so that book values have been used as a second-best alternative.

The Agency determined the eligible operation and maintenance costs for 2003 on the basis of the purged data from the profit-and-loss statements relating to the particular service, or on the basis of the actual costs for the period from January 2001 to June 2002.

5.4.3 Efficiency Analysis

AERS opted for a building blocks approach whereby benchmarking only plays a role with respect to OPEX, and only as far as controllable cost is involved. The methodology used for the OPEX benchmarking exercise has been a crosscheck of both COLS and DEA, which were applied according to their canonical version as explained in the theoretical part of this paper.

Distribution OPEX data include: salary costs, direct network costs (ordinary maintenance costs, (third party) services, materials), and an allocation of overheads. DOPEX data do not include retail supply costs, annual depreciation, energy purchase costs and any pass-through costs from upstream companies. Controllable DOPEX data include salary costs, operation and maintenance costs and other controllable costs. Fees and other items that are not controllable by the companies are excluded from the DOPEX data.

The sample includes foreign companies. An average 80% efficiency catch-up of comparable companies is required in the first regulatory period in order to reduce the differences in the efficiency between domestic and foreign companies. The companies have to reduce costs between 4 to 9% per annum, depending on their initial levels of relative efficiency (AERS, 2004).

6 Short Practical Examples

To illustrate the process of X factor computation and the difference between the building blocks and totex approach respectively, two short practical examples are now supplied.

6.1 Building Blocks

6.1.1 Regulatory parameters

As can be seen, the main regulatory parameters are the OPEX efficiency score (assumed to be 75%) and the WACC (assumed to be 10%). Furthermore, for simplicity, a depreciation period of 25 years is assumed for all asset categories. Notice that in practice, each asset category may have a different depreciation period. Finally, the regulatory period is 4 years. We now discuss the different building blocks accordingly.

6.1.2 OPEX

The initial OPEX is given as 100. Using benchmarking analysis, an efficiency score of 75% has been obtained. This implies that, at the end of the regulatory period, OPEX should have been reduced to 75%x100 = 75. This can be translated in terms of an annual reduction target for opex equal to $1-(75\%)^{1/4}$ =6.9% Here, the root of ¼ follows from the fact that we are dealing with a regulatory period of 4 years. This corresponds to $(1-6.9\%)^4 = 75\%$.

Applying the annual reduction target of 6.9% results in an OPEX pattern which reduces from 100, at the beginning of the regulatory period, to 75 at the end of the period. This can be called initial X factor but as we will see below differs from the calculation of the final X factor.

6.1.3 Investment/Depreciation

A distinction can be made between two categories of depreciation namely for previous investment (before the regulatory period) and for new investments (during the regulatory period). Depreciation costs for previous investments are given as these directly follow from the initial RAB (defined as net asset value) of the company just before the regulatory period. A remark that should be made here is that in this example, we assume that the regulator allows the company to recoup all its investments made before the regulatory period. In practice, it may be that the regulator makes adjustments to the initial RAB value if it disallows certain investments already undertaken by the company.

Depreciation costs for previous investments are equal to 20, which follows from dividing the initial RAB (of 500) by the depreciation period (25 year). For simplicity, we assume here that no capital disposals take place and that all assets are still younger than 25 years during the course of the regulatory period.

Regulatory parameters					
Opex Efficiency Score	75%				
WACC	10%				
Depreciation period	25 years				
Annual reduction in opex	6.9%				
	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**
OPEX					
Initial Opex	100				
Opex efficiency score	75%				
Implied annual reduction target	6.9%				
Required Opex	**100.0**	**93.1**	**86.6**	**80.6**	**75.0**
Investments / Depreciation					
Required Investment		**10.0**	**30.0**	**25.0**	**25.0**
Required Depreciation					
From prevision investments		20.0	20.0	20.0	20.0
From investments in year 1		0.4	0.4	0.4	0.4
From investments in year 2			1.2	1.2	1.2
From investments in year 3				1.0	1.0
From investments in year 4					1.0
Total Required Depreciation		**20.4**	**21.6**	**22.6**	**23.6**
RAB/Returns					
Starting RAB	- / -	500	490	498	500
Plus: New investments		10	30	25	25
Minus: Depreciations		20	22	23	24
Ending RAB		490	498	500	502
Average RAB	**500.0**	**494.8**	**493.8**	**499.2**	**501.1**
Required Returns (WACCxRAB)	**50.0**	**49.5**	**49.4**	**49.9**	**50.1**
Required Revenues					
Opex	100	93.1	86.6	80.6	75.0
Depreciation	20	20.4	21.6	22.6	23.6
Returns	50	49.5	49.4	49.9	50.1
Non-controllable costs	10	12.0	8.0	18.0	12.0
Required Revenues	**180.0**	**174.9**	**165.6**	**171.1**	**160.7**
Allowed Revenues					
Demand	180	185	190	195	200
Price (X-factor applied)	1	0.95	0.90	0.85	0.80
Allowed Revenues	**180.0**	**175.2**	**170.3**	**165.5**	**160.8**
Discount factor:	1.00	0.91	0.83	0.75	0.68
Required Revenues - PV	714.2				
Allowed Revenues - PV	714.2				
X-factor	5.3%				
NPV	**(0.00)**				

Figure 13 *Example of X factor computation under the building blocks approach.*

For the new investments, depreciation costs will vary annually, as a function of the investment pattern of the company. In this specific case, we assume that the company invests in the years 1 till 4 amounts of receptivity 10, 30 25, and 25. As can be observed, based on a depreciation period of 25 years, this results in a depreciation cost for each respective year of 0.4, 1.2, 1.0 and 1.0. Annual depreciation costs can then be simply derived by summing up the depreciation costs corresponding for both, previous and new investments, for each successive year.

6.1.4 RAB/Returns

The annual RAB is a function of three factors namely the initial RAB (i.e. the RAB right before the regulatory period starts), the new investments that are added to the RAB, and the depreciation costs (for existing and assets) that are deducted from the RAB. Using this information, the starting RAB (at the beginning of the regulatory year) and the ending RAB (at the end of the regulatory year) can be computed for each respective regulatory year. The average RAB is then defined as the average of the starting and the ending RAB. The annual required returns then follow directly from multiplying the WACC (in this case 10%) with the average RAB for that year.

6.1.5 Required Revenue

The required revenue is the sum of the individual building blocks namely OPEX, depreciation, and returns. Also, the required revenue should take into account the non-controllable costs which are directly passed through the tariffs. The non-controllable costs are typically based on a forecast. Later on, the regulator may choose to correct for any differences between forecasts and actual non-controllable costs.

The sum of the individual building blocks results in a set of “unsmoothed” revenues i.e. they will not result in an annual price that changes annually by the same constant factor (the X factor). Thus, the required revenues need to be “smoothed” out. The smoothed revenues are defined as the allowed revenues.

6.1.6 Allowed Revenue

As said before, the required revenues need to be translated in terms of allowed revenues. Here, allowed revenues are defined as the product of the demand and the price for each successive year. The example implies an application of price cap approach.[50] Demand follows from demand forecasts. Optionally, the regulator can choose to correct afterwards for any differences between forecasted and actual demand. The annual price follows from the

[50] The smoothing can be done using by smoothing the allowed revenue without explicit consideration of demand forecast in the smoothing formula. In this case the X will refer to the allowed revenue and exactly the allowed revenue will be smoothed. Then depending on the demand forecast, the annual price change may not follow the X factor.

initial price (p_0) and the X factor. The initial price P_0 (which is assumed to be 1 in this case) is given as is the price charged by the company in the year preceding the regulatory period. The price in each successive year is found by multiplying the price of the preceding year by the X factor.

6.1.7 Discount factor/Present Value Computations

The required revenue is the level of revenue that the regulator would allow the company to earn in principle. The allowed revenue is the revenue that the company will actually earn (apart from any demand forecast errors). The allowed revenue is based on a constant change in prices equal to the X factor. The condition for this X factor is that the net present value of the two revenue streams (required and allowed revenues) should be equal to zero. This can be done by setting the X factor such that the difference between the present values of the two revenue streams is equal to zero. The discount rate used for this NPV computation is the WACC (10% in this case). For each year, a discount factor can be computed, being equal to DF = 1/ $(1+ \text{WACC})^t$ where t is the regulatory year.

One could in principle solve the X factor in an analytical way by considering the following equation:

$$NPV = \sum_{t=0:N} \left(\frac{RR(t)}{(1+WACC)^t} \right) - \sum_{t=0:N} \left(\frac{p_0 \cdot (1-X)^t \cdot q(t)}{(1+WACC)^t} \right) = 0$$

As can be seen, this comes down to solving a polynomial equation of the order n where n stands for the number of years of the regulatory period. Finding an analytical solution for a polynomial of order higher than 2 is typically not so practical. In practice this problem can be overcome by solving the X factor through an iterative process. By gradually increasing or decreasing the value for the X factor, one can observe the impact on the level of the NPV. If the NPV is equal to zero, the appropriate X factor has been found. Such an iterative process is usually programmed into spreadsheet programs (e.g. “Goal Seek” under MS Excel).

In the presented calculation the calculated (final) X factor has a double function:

- it incorporates the implied efficiency increase in the OPEX stream of numbers
- it smoothes financially the price path over the years of the regulatory period.

6.2 Total Cost Analysis (TOTEX)

6.2.1 Regulatory parameters

The number of regulatory parameters under the TOTEX approach is less than under the building blocks approach. Here, the only relevant parameter is the efficiency score for the total costs of the company under consideration. In this specific example, the TOTEX efficiency score is given as 85%. This corresponds with an annual reduction target of 4%.

6.2.2 TOTEX Targets

Under the TOTEX approach, no distinction is made between the individual cost items (OPEX, depreciation, and returns). Instead, the initial total costs (being the sum of these 3 elements in the year before the regulatory period) is considered as a whole. These costs are used in the benchmarking analysis and the resulting efficiency score is derived. The TOTEX target for each year is then found by translating the TOTEX efficiency score into an annual TOTEX reduction target. This is done in the same way as the computation of the OPEX reduction target explained earlier under the building blocks approach.

6.2.3 Required Revenues

Required revenues are defined as the sum of the TOTEX targets and the non-controllable costs. Similar as under the building blocks approach, the regulator may apply a correction ex post if actual non-controllable costs turn out to be different from forecasted values.

6.2.4 Allowed Revenues

The next step in computing the X factor is to determine the allowed revenues. Note that in contrast with the building blocks approach, here the regulator does not assume any demand forecasts but assumes demand to be fixed. The reason for this is the nature of the totex approach. In contrast with the building blocks approach, the regulator does not determine the appropriate level of costs (and hence revenues) for the company for each year. Here, rather, the regulator takes a snapshot of a single year (year 0 in this case) and determines what, on this basis, should be an efficient level of costs for the company to operate at. Thus, everything is assumed on the basis of the initial year 0: costs, efficiency, and demand.

Note that the practical application of TOTEX benchmarking should always be considered in the context of the overall price control approach. The regulatory formulas using TOTEX-based X factors contain usually explicit terms for revenue adjustments in function of pre-determined network cost drivers as e.g. energy throughput, customer numbers etc. The demand forecast is used to adjust annually the allowed revenue according to the regulatory formulas. This adjustment aims to remunerate regulated companies for any additional cost (OPEX and CAPEX) resulting from demand changes in the regulatory period.

6.2.5 Discount factor/Present Value Computations

The further process of computing of the X factor is the same as under the building blocks approach. This is done by equating the present values of the required and allowed revenue streams. Using an iterative process, the X factor can then be derived.

Some regulators do not apply smoothing under TOTEX benchmarking, e.g. in Norway and Austria. They set the established annual TOTEX reduction automatically equal to the X factor. Differently, the Dutch regulator used smoothing in her TOTEX benchmarking.

Regulatory parameters					
Totex Efficiency Score	85%				
Annual reduction in totex	4.0%				
	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Totex Targets					
Opex	100.0				
Depreciation	70.0				
Returns	150.0				
Totex targets	**320.0**	**307.3**	**295.0**	**283.3**	**272.0**
Required Revenues					
Totex targets	320.0	307.3	295.0	283.3	272.0
Non-controllable costs	10.0	12.0	8.0	18.0	12.0
Required Revenues	**330.0**	**319.3**	**303.0**	**301.3**	**284.0**
Allowed Revenues					
Demand	330	330	330	330	330
Price (X-factor applied)	1	0.96	0.93	0.90	0.87
Allowed Revenues	**330.0**	**318.3**	**307.1**	**296.3**	**285.8**
Discount factor:	1.00	0.91	0.83	0.75	0.68
Required Revenues - PV	1,291.0				
Allowed Revenues - PV	1,291.0				
X-factor	3.5%				
NPV	**0.00**				

Figure 14 *Example of X factor computation under the totex approach.*

7 Results from the Questionnaire

The questionnaire which was developed by KEMA and sent to all ERRA members consists of 14 main questions on the application of incentive-based regulatory methods. In the following, the received feedbacks are described by country. The description is purely based on the regulatory responses and is not seeking any completeness in terms of describing the properties of the regulatory regimes in the ERRA countries.

A summary of the results and derived conclusions is in chapter 8.

7.1 Albania

In June 2005, the Albanian Regulatory Authority (ERE) approved methodologies for generation, transmission, distribution and captive consumers' tariffs. In the Albanian electricity market, distribution and supply functions are not separated and still monopoly of the state owned company KESH sh.a.

The methodologies were intended to be implemented for the first time in 2005, however for the purpose of reviewing captive consumers' electricity prices only. In 2006 an average transmission tariff was approved according to the transmission methodology. The tariff is regulated via annual cost reviews.

Since the regulator was established recently (2005), it has not gained experience yet in using any kind of (incentive) regulation. However, the regulator plans to introduce it in the coming years. Although the X-factor should be determined according to the regulator's methodology, currently no efficiency increase requirements are applied in Albania. Consequently, no efficiency assessment studies have been conducted yet. Nevertheless, selecting an appropriate benchmarking method for the future is on the agenda. According to the regulator, the future regulatory system will neither include quality of supply issues nor any consideration for structural differences between regulated companies.

7.2 Armenia

In Armenia, a cost-plus approach is used. Until January 2002, network regulation was based on tariff margins denominated in USD. Since 2004, the Public Services Regulatory Commission of Armenia (PSRC) is responsible for the methodology to regulate network charges.

OPEX is calculated on the basis of the actual OPEX contained in the financial statements of the companies. Depreciation is calculated as straight line depreciation. For the existing assets the depreciation rate is set at 10 % and for the new assets at 4 %. The rate of return is set to 17 % until 2010 and will not exceed 12% after 2010. Network losses allowed in electricity prices are gradually to be lowered, from 17% in 2004 to 13% in 2008.

7.3 Bosnia and Herzegovina

The regulatory authority in Bosnia and Herzegovina applies a rate-of-return regulation approach. Incentive regulation instruments and application of benchmarking tools are not used.

7.4 Bulgaria

In Bulgaria, the transmission price control is based on rate-of-return regulation. For distribution networks, the regulator (State Energy and Water Regulatory Commission, SEWRC) introduced a revenue cap in 2005, where 2006 is the first year of the first regulatory period, fixed at 3 years.

The annual adjustment of the revenue requirements is calculated according to the following formula:

$$\mathrm{Re}\,vR_t = \mathrm{Re}\,vR_{(t-1)} \times (1 + I - X) + Z - Y\ ;$$

where:

$RevR$ represents the annual revenue requirements of the company

I is the inflation for a 12-month period preceding the submission of application

t reflects the rate period

X is the efficiency improvement factor

Z is the adjustment for differences between forecast and actual power purchase costs for the previous year, and

Y represents service and energy quality adjustment for the previous year performance.

The efficiency improvement factor (X-factor) is calculated on the basis of actual efficiency improvements achieved by the electricity distribution companies during the previous regulatory period. Moreover, SEEWR may perform benchmarking studies using national and regional data. The regulator plans to apply X factors from the beginning of the second regulatory period. To date, Bulgaria has not yet gained experience in the determination of X-factors using efficiency assessment studies.

7.5 Estonia

The Estonian regulator, the Energy Market Inspectorate (EMI) applies a price cap regulation using an RPI-X formula. Annual prices during the regulatory period are calculated on the basis of prices from the previous year, the retail price index and an efficiency factor determined by the regulator.

For the biggest Estonian network company this kind of regulation started on 01.04.2005, and will end after three years on 31.03.2008.

EMI uses quantitative methods to determine the X factor. Within benchmarking, it compares constant[51] costs (separately OPEX and CAPEX) and network losses of different companies. EMI applies a regression analysis to benchmark the cost against selected output parameters such as network length and energy throughput. Those companies whose constant costs or network losses are above the regression line[52] are classified as inefficient and must reduce their cost or network losses by the measured distance to the regression line to become efficient.

State taxes (for licenses, and general taxation as well) are classified as non-controllable by the companies, and excluded from the benchmarking.

The regulator has introduced three benchmarking groups depending on annual sales (0-10 GWh, more than 10 GWh but less than 100 GWh, more than 100 GWh per year). Quality of supply is not considered in the benchmarking.

EMI found that the Estonian electricity companies have a similar operating environment and the only factor to be considered explicitly is the density of supply, defined as network length 0.5 x distributed energy 0.5.

A general X factor does not exist. Instead, the X factor is derived from separate efficiency targets imposed on different cost streams (constant cost, network losses etc.).

7.6 Georgia

The main method used in Georgia is cost plus (rate of return). Starting from July 2006 the plan is to introduce maximum prices for generation. The new legislation allows for such maximum tariffs for the networks and they can be applied in the near future.

[51] The wording replicates the response of EMI.

[52] From the response it is not clear whether the regression analysis applies OLS or COLS.

There are targets for network losses which could be significantly lower than actual losses. The regulator applies a comparative analysis between actual and planned parameters, wherein total costs (including capital costs) are included.

7.7 Hungary

The Hungarian Energy Office (HEO) uses a price cap-based network regulation including an incentive for supply quality in distribution. The inclusion of network investments in the RAB is done annually. Currently, Hungary is in its 3^{rd} 4-year regulatory period, and in the 2^{nd} year of this 3^{rd} period (2005-2008).

HEO has implemented an explicit incentive scheme for quality regulation. The Hungarian system includes direct integration of quality performance into the price caps. Regulated distribution charges should be decreased by 0.5% if any of 3 pre-selected indicators for supply quality deteriorates by more than 5%, but less than10 % (compared to set target values).

In case several indices are worsened, the effect is cumulated. In case one indicator improves by more than 10% and the company is not forced to reduce its distribution charges because of no deterioration in any other indicator, its cap on the allowed rate of return (set equal to 1.5 x allowed rate of return) is going to be increased by 10%. The allowed rate of return is set at 7.1% and the allowed return is computed as a product of the allowed rate of return and the net asset value based on replacement cost.

In Hungary, the X-factor is determined as $1.8 <= X <= 2.2$ in electricity price regulation, whereby system operation is excluded. Thereby, the X-factor value reduces inflation, taken into account in the process of regular yearly price corrections (and setting starting prices in the regulation period). Quantitative methods to study the efficiency position of the companies are currently not used.

7.8 Kazakhstan

Regulation in Kazakhstan is based on a cost plus method. The method determines the allowed cost by categories to be considered in the revenue requirements. The allowed profit is calculated as an allowed rate of return on the assets in service. There is a tariff scheme that discloses the cost categories and return per tariff component depending upon the services provided. There is a penalty of 5% for non-compliance with the tariff scheme.

Usually the tariffs are set for 3 and more years. The tariff path should consider planned investments. The actual investment performance is monitored and regulation provides options to retain the gains resulting from cost savings.

There is a pilot project for the establishment of comparative analysis, based on actual and planned indicators, whereby OPEX will be used. The Agency of the Republic of Kazakhstan for the Regulation of Natural Monopolies (ANMR) plans not to exclude any costs from this analysis and to apply a multi-factor model. Possible factors are area, customer density, asset volume, and asset value. In addition factors like landscape, climate conditions etc. are intended to be used.

7.9 Kosovo

The regulator in Kosovo (ERO) is currently introducing revenue cap-regulation, at first with a regulatory period of three years, starting in 2007. Within the regulatory formula, the X-factor represents the real annual change in allowed revenues required to equalise the present value of allowed costs and allowed revenues over the price control period. The formula is:

REVt = REVt-1*(1 + CIt – X)

where:

REVt is the allowed revenues (expressed as maximum allowed revenue, average unit revenue or tariff basket)

CIt is an index of change in costs of inputs (%), and

X reflects the real change in allowed revenues (%) and is to be determined by the regulator.

The role of the X-factor is to incorporate expectations of efficiency improvements, but will not necessarily equal the expected annual efficiency gain.

In Kosovo there is only one electricity company. In the future ERO will take into account benchmarking data from comparable companies in comparable surrounding countries. Thereby, ERO will undertake a distinction between controllable and non-controllable costs when defining the X-factor. The list of non-controllable costs will be defined soon, in consultation with the electricity company.

At a later stage, the measurement of supply interruptions could be included into the regulation in order to take into account quality of supply data.

7.10 Latvia

The Public Utilities Commission (PUC) in Latvia regulates network tariffs on a cost basis at the beginning of a 3-year review cycle and sets a price cap during this review cycle. Electricity transmission network regulation is currently in its first year of the second tariff review cycle, whereas electricity distribution is in the third (last) year of its first tariff review cycle.

At the beginning of each tariff review cycle the tariff is set to be cost-based. During the 3-year tariff review cycle the price cap value is calculated for each year according to the formula $TGV_t = TGV_{t-1}*(1+ PCI - X)$.

The X factor represents the necessary efficiency gains. Its value is based on historic efficiency gains, adjusted for possible one-off events and estimated expected changes in efficiency resulting from loss reduction and scale effects.

The historic efficiency is evaluated as total factor productivity (Tornquist index). Hence, the companies' relative efficiency and the general productivity increase are not explicitly distinguished.

In the course of benchmarking, networks losses of the investigated company are compared with actual historic values and the losses of the other companies. Non-controllable costs, the company scale and the companies' operating environment are not considered, neither are quality aspects. However, the latter issue is likely to be included in the price cap formula when the necessary quantitative indicators will be approved.

7.11 Lithuania

The Lithuanian National Control Commission for Prices and Energy (NCC) uses a hybrid cap and currently is in its second year of the second regulatory period.

Within hybrid cap regulation, the initial revenue level is set for 3 years and the allowed revenue is annually adjusted by the following factors:

- indexation - inflation (CPI) and efficiency (X-factor)
- volume adjustment
- contingency
- correction (under/over revenue recovery).

The revenue cap formula is given below.

T't = ((Pp*NKt*EKt*IKt) / Et) ±Kt

where:

Pp is the initial revenue level (average) for 3 years

NKt, EKt, IKt, Kt represent contingency, volume adjustment, indexation and correction factors in year t, and

Et is the electricity volume in year t.

The X factor represents the anticipated efficiency increase by the regulator. It is determined by the formula:

X=CPI/2 (CPI = consumer price index).

Since there are only two distribution system operators, complex quantitative methods to study the efficiency position of the companies are not applied, as they are deemed unnecessary by the Commission. Also, relative efficiency and general productivity increases are not distinguished. The Commission studies investment efficiency through visits to the network companies and reports.

The Ministry of the Economy approves Rules on Quality Requirement. Minimum standards will be introduced by 2008. If investments are not enough to ensure the quality requirements are met, the regulator may undertake a correction in the profit sharing mechanism.

7.12 Macedonia

The Macedonian Energy Regulatory Commission (ERC) uses a revenue cap to regulate transmission and a hybrid method (price cap and revenue cap) for distribution. The first regulatory period started on 01.01.2005 and will end on 31.12.2007 (three year period). The main principles followed by the Commission are:

- adequate price setting as a result of minimizing costs
- optimal investment (better planning of investment and optimal financing)
- stable prices
- better quality of supply as a result of controlling
- stimulation of the regulated company's efficiency

The regulatory formula for transmission is:

MARt = MARt-1*(1+CPI)*(1-X)-Kt – St

The regulatory formula for distribution is:

MARt = [MARt-1*(1+CPI)*(1-X)-Kt] * a+ (1-a)*Pt – St - Z

The value of the X factor for the first regulatory period is set at zero because of missing data on the determinants of efficiency in former periods.

Since there is only one company in the country per subset, quantitative efficiency studies on the relative efficiency position of companies are not easy. Instead, normalised costs are used in order to limit the amount of cost within the scope of each company. Existing benchmarking methods have not been used yet, because ERC is lacking adequate data available about companies comparable to the one in Macedonia.

7.13 Montenegro

The Energy Regulatory Agency of Montenegro (ERA) intends to introduce cost plus regulation, and in case of a multiyear tariff period, a price cap. This sort of regulation has not been started yet. ERA intends to apply the price cap approach including CPI-X, which means that allowed regulated revenue for the following year equals the allowed revenue of the previous year plus inflation, minus an efficiency increase factor, established by ERA. Thereby, the X factor is the anticipated efficiency increase.

Quantitative methods to study the efficiency position of the companies are not used yet.

7.14 Poland

The Polish Energy Regulatory Office (ERO) introduced an incentive-based regulatory system consisting of revenue and price cap, including an RPI-X formula. The regulatory period lasts 1 to 5 years.

Components of the regulated revenue of distribution activities are:

Rev = OPEX + D + RC + L + PC +TAX

Where:

OPEX stands for operating and maintenance costs

D is depreciation

RC represents the return on capital engaged in activity;

L is the cost of the commercial and technical losses

PC means pass-through costs; and

Tax is taxes (local property taxes).

The X factor is part of a general regulatory formula which is established in the tariff ordinance:

$$Cwn = P / S < Cwn\text{-}1\ [1 + (RPI - X)/100]$$

Where:

Cwn is the indicative price in the n-year

P is the regulated revenue in the n-year

S is sales in the n-year

Cwn-1 represents the indicative price of the (n-1)-year

RPI means Retail Price Index; and

X is the efficiency improvement coefficient approved by ERO.

ERO uses quantitative methods to study the efficiency position of the companies and distinguishes between relative efficiency and general productivity increases. As for benchmarking methods, COLS (Corrected Ordinary Least Squares), OLS (Ordinary Least Squares) and DEA (Data Envelopment Analysis) are implemented.

The input and output of the benchmarking model is specified by a Principal Components Analysis (PCA), which is based on 27 characteristic variables. Variables mainly reflect:

- length of line at different voltage levels
- capacity and number of transformer stations
- number of delivery places
- delivery quantity to different customer groups at low voltage (households and small commercial customers)
- number of customers at low voltage
- transmission energy exchange
- average net peak.

Operating and maintenance expenditure, losses (technical and commercial) and investment (as an element of remunerated capital) are included in the benchmarking model.

Furthermore, capital cost for benchmarking is the sum of depreciation plus return: RC = r * RAB,

Where:

RC is the return on capital invested, cost of capital is determined as the WACC and RAB is the regulatory asset base (book value).

As an example, the formula for 2006 is as follows:

D (2006) = D (2004) + rA * (I netto 2005 + I netto 2006)/2,

where:

D (2006) is the planned depreciation in 2006 r.

D (2004) is depreciation in 2004 r. according to financial statements

I netto 2005 reflects the planned and approved net investments in 2005

I netto 2006 reflects the planned and approved net investments in 2006, and

r is the depreciation rate, average 4,5%.

Taxes and levies are excluded from the efficiency analysis. Neither company scale nor quality of supply is considered in the analysis. The regulator approves tariffs with binding distribution service standards described in an ordinance. The operating environment of the companies is considered through variables in the benchmarking analysis.

The efficiency scores resulting from the efficiency analysis are converted into X factors by defining the best performer, which has the lowest improvement in efficiency (cost reduction), whereas the worst company has the biggest cost reduction.

7.15 Romania

The Romanian Electricity and Heat Regulatory Authority (ANRE) uses a price cap methodology, including a price basket. 2006 is the second year of the first 3-year regulatory period. By exception the first regulatory period is of three years; each of the next regulatory periods will last for five years.

The main formula for price regulation is: 1 + CPI –X, whereby the price increase is capped to a maximum value of 18% per year. The price increase means a negative X factor which can result from intensive CAPEX plans, non-cost reflective prices from the past etc.

The annual allowed revenue includes OPEX (controllable Opex will be yearly reduced by 1%, called the 'initial X-factor', and non controllable Opex will be added on top) plus CAPEX (expressed as depreciation plus return on assets, RRR x BAR).

The regulatory asset base (BAR) includes:

- the net value of fixed and current assets commissioned following prudent investment
- a value allowed for the working capital to cover the short term financial liabilities of the distribution companies.

BAR includes only assets used by the distribution operator to provide the distribution service. The regulated rate of return is calculated in real terms, pre-tax, on the basis of a weighted average cost of capital. For the privately owned distribution operators the value of the RRR in real terms, pre-tax will be 12% for each year of the first regulatory period (2005-2007) and 10% for each year of the second regulatory period (2008-2012). In the case of wholly state owned distribution operators, the value of the RRR can be reduced given a zero country risk and private investor risk.

For the first regulatory period, an initial X factor of 1% yearly is applied. This initial X factor has two parts: X ‘catch up’ and X ‘frontier shift’. From the third regulatory period onwards (2012), DEA analysis is planned.

In the benchmarking model, OPEX as an input variable and the number of customers, network length etc. as output variables are considered. Controllable OPEX are included, whereas capital costs are excluded, which is justified by high investment requirements in the Romanian distribution network.

The following non-controllable costs are excluded from the benchmarking:

- costs due to taxes and royalties set according to the legal provisions in force or by the local authorities
- regulated costs regarding special expenses
- contributions to the health fund, special fund and other similar contributions related to the wages but excluding the alternative health and pension systems
- the regulated transformation/connection, distribution costs generated by the use of transformers/substations, lines owned by other companies
- extraordinary costs determined by force majeure
- severance payments, according to legislation in force
- costs generated by the restriction to cut the power supply to certain commercial companies on the basis of Government Decisions. Only that part corresponding to the distribution service not covered by bank guarantees and/or working capital is included.
- costs due to losses from receivables and various customers for the distribution service
- additional losses due to the use of the distribution network by the transmission operator, justified based on specific studies
- compensation costs established by court decisions, if the parties do not mutually agree.

Starting 2008 (the second regulatory period), an incentive mechanism regarding quality will be introduced. For this purpose, a quality S factor is to be determined. The price cap formula will then become: 1 + CPI –X +/- S.

According to ANRE, variables to consider differences in the companies’ operating environment were intended to be considered in the benchmarking process. ANRE could not find any significant correlation between them and controllable OPEX in their first benchmarking analysis.

Efficiency scores resulting from the efficiency analysis are converted into X factors by combining quantitative and qualitative steps. The catch up portion of the initial X is also calculated.

7.16 Serbia

According to pricing methodologies that are being developed by the Regulatory Agency a cost plus methodology, based on the building blocks approach, will be implemented. This method will be in use during the transitional phase, after which incentive regulation will be implemented.

7.17 Turkey

In Turkey, the Energy Market Regulatory Authority (EMRA) introduced a performance-based revenue cap to regulate transmission and distribution networks.

For transmission, 2006 is the starting year of the first regulatory period which will last three years. For distribution, the first regulatory period will start in line with the privatization of distribution regions. The expected duration of the first regulatory period is 4 years until the end of the year 2010.

The “building blocks approach” has been adopted for both transmission and distribution activities. The allowed revenue includes OPEX plus CAPEX (return and depreciation) plus stranded costs.

During the first regulatory period (2006-2008) the X-factor for transmission has been set equal to zero. After restructuring of the former Turkish distribution company (TEDAS), 20 new distribution companies have been established.

These companies will be benchmarked and the assessed efficiency improvement potentials will be used in the regulatory formulas. EMRA will apply Corrected Ordinary Least Squares (COLS) and Data Envelopment Analysis (DEA). In order to specify the input and output parameters of the benchmarking model, econometric techniques and economic assumptions with respect to the cost function will be used. Non-controllable costs are replaced by a dummy variable. The company scale is considered in the DEA specification, quality of supply issues and environmental differences are not. For the future, international benchmarking is planned.

CAPEX is not included in the benchmarking. Instead, distribution companies have to submit detailed investment proposals.

7.18 Ukraine

In the Ukraine, rate-of-return regulation is used for the majority of distribution networks. In 2005, five Ukrainian distribution companies were privatised. For those, some incentive schemes apply.

These five private distributors should provide information on their OPEX by component (labour, materials, etc.). The basis year is 2002, but can be changed by legislation. The distribution companies may also apply for indexation of the OPEX components: for materials, the wholesale price index is used and for labour, the retail price index. E.g. labour cost is indexed by the following formula:

$L_{i+1} = L_i \times (1 + \text{ИРЦ} - X) \pm Z$

Where:

L_i	is labour cost in year i
L_{i+1}	is labour cost in year i +1
ИРЦ (RPI)	is the Ukrainian retail price index
X=0	is the efficiency factor, which is set at zero initially, and
Z	reflects an adjustment for non-controllable cost.

The prerequisites to conduct an efficiency analysis are available in the Ukraine. The regulator is familiar with the different benchmarking techniques and the concepts of relative efficiency (catch-up effects) and general productivity improvement (frontier shift). The regulator has performed “shadow” efficiency analysis experimenting with TFP, OLS, COLS, DEA and SFA. The results from these efforts, however, are not used and the X factor is set equal to zero. The input in the efficiency model is the distribution OPEX, where OPEX is defined with and without depreciation. The output is represented by energy throughput, number of customers and network length.

Investment efficiency is not investigated. Quality of supply is not included in the model because of missing data. Non-controllable costs are separated. The company scale is considered by using a VRS mode in the DEA method. In order to increase the homogeneity of the sample, NERC includes only regional distribution in the benchmarking. The cities of Kiev and Sevastopol are therefore excluded.

8 Preliminary results and conclusions

8.1 Overview

In the last decade, incentive regulation has become common practice in many European countries. Information on these regulatory regimes is widely available and can be studied. The situation in the ERRA member countries is not homogenous in terms of development, methods and problems faced.

In order to investigate the regulatory status quo in the ERRA countries, and especially the application of incentive mechanisms including the use of efficiency improvement factors (X-factors), KEMA developed a questionnaire which was sent to all ERRA members. This questionnaire contained a number of questions related to the main features of the price control methods and, more specifically, to the properties of the efficiency analysis (benchmarking) of network operators in these countries.

The completeness of the responses is satisfactory and provides a reasonable overview of the current regulatory practices and trends in the investigated countries. It is evident that the countries strongly differ in terms of development and usage of incentive regulation and efficiency analysis in their regulatory frameworks.

20 of the 23 full ERRA members answered the questionnaire. We did not receive responses from the regulators of the Kyrgyz Republic, Moldova and Mongolia. Almost all countries described their regulatory system comprehensively and educated conclusions could be drawn. Being in the middle of the development of a new tariff system, the Croatian regulator did not disclose information on their regulatory development. Similarly, the Russian regulator did not complete the questionnaire, but rather replied via e-mail indicating that the Russian energy market is currently restructured and the introduction of incentive regulation is not a priority.

In the following we summarise the results and provide some conclusions.

8.2 Clusters found

8.2.1 Overview

Based on the responses to our questionnaire, the countries in the ERRA region can be divided into three groups reflecting the level of application of incentive mechanisms and efficiency analysis in their current price control schemes. We grouped the countries in the following clusters:

- incentive regulation schemes with implemented benchmarking analysis;
- incentive regulation schemes without implemented benchmarking analysis;
- no incentive regulation.

8.2.2 Incentive regulation with implemented benchmarking

The regulators that have implemented incentive regulation schemes (price or revenue caps) and benchmarking are Poland, Estonia and Latvia. The regulators perform quantitative analysis to compute and set the X-factors. The efficiency analysis uses traditional assessment techniques, such as parametric and non-parametric frontier methods.

The Polish regulator applies all available non-parametric and econometric techniques to compute the efficiency. The Estonian regulator applies a simplified regression analysis to benchmark the companies. Latvia uses just a Tornquist TFP index and does not distinguish between relative efficiency and catch-up effects. None of the countries includes quality of supply in the benchmarking exercise.

8.2.3 Incentive regulation without implemented benchmarking

Hungary and Lithuania have functional incentive regulation, but do not apply any quantitative studies to assess the value of the X factors used in the regulatory caps. In Lithuania, the X factor is merely linked to the inflation index (50% of annual inflation). National benchmarking is impossible, as only two distribution companies exist. In Hungary, the X factor can range between 1.8% and 2.2%, however no quantitative studies are used to support the factor's setting.

Bulgaria and Romania have established incentive regulation, but did not apply efficiency analysis for the first regulatory period to compute efficiency scores and set X factors. In Romania, ANRE decided to require an efficiency increase of 1% (per year) on controllable OPEX. In Bulgaria the X factor was set at 0% in the regulatory formulas due to lack of time, and appropriate data and tools to measure efficiency. For the second regulatory period, both countries plan to implement benchmarking analysis to support the setting of X factors.

Kosovo and Macedonia have opted for implementation of incentive regulation, using hybrid revenue caps. No benchmarking exercises have been carried out in these countries. Moreover, the implementation of incentive regulation is still undergoing.

In 2005, the Ukraine has introduced an incentive scheme for individual OPEX components. The new scheme contains an efficiency factor. The regulator has performed "shadow" efficiency analysis experimenting with TFP, OLS, COLS, DEA and SFA. The results from these efforts, however, are not used and the X factor is set equal to zero.

8.2.4 No incentive regulation

Finally, a number of countries, like Georgia, Armenia, Albania, Bosnia and Herzegovina, Kazakhstan and Montenegro apply cost-of-service (rate of return) regulation. Similarly, Serbia applies cost-of-service regulation as a transition solution for 2 years – afterwards, it should implement tariff basket caps. Although these countries do not apply fully-fledged incentive regulation, some incentive elements are used in the context of cost-of-service regulation, e.g. targets for the reduction of network losses.

8.3 Conclusions

8.3.1 Implementation of incentive regulation

The establishment of incentive regulation in terms of conceptual development and practical implementation requires serious efforts and time. Moreover, the success of incentive price control schemes is pre-determined to a large extent by the degree of understanding and acceptance by regulated companies.

Therefore, the introduction of incentive regulation should follow the evolution of knowledge, structural and price reforms. More importantly, the introduction of incentive regulation should not be considered as a "fashion trend" that can work everywhere. The decision on whether and when to move to incentive regulation, should correctly address: the sector's status quo, problems, and priorities in the respective country.

8.3.2 Benchmarking methods

The informational asymmetry problem between the regulator and its regulated agents has been widely recognised by academics and practitioners. Lack of information about the companies' efficiency potential prevents the regulator from setting optimal prices and performance standards. Benchmarking is a powerful tool to reduce this informational asymmetry.

The countries using (or experimenting) with efficiency analysis use the established and common quantitative methods: TFP, COLS, SFA, DEA. Furthermore, many regulators (ERO in Poland, ANRE in Romania, EMRA in Turkey, and NERC in Ukraine,) apply not just one method for efficiency analysis, but cross-check the results with the help of several efficiency assessment techniques. Recently, this has also been observed in Western Europe, e.g. in Austria and Germany (planned).

We completely support such an approach combining DEA and one econometric technique, preferably (but not necessarily) SFA.

8.3.3 Implementation of benchmarking

In contrast to some Western European countries (Norway, the Netherlands, Austria), where the cost input in the benchmarking model integrates OPEX and CAPEX in one TOTEX variable, the majority of ERRA regulators use a building blocks approach. Under this approach, (controllable) OPEX is benchmarked and CAPEX is separately checked for efficiency outside of the benchmarking analysis. The results of OPEX benchmarking and CAPEX efficiency checks are used to establish the annual revenue requirements during the regulatory period.[53]

Ideally, benchmarking should use total controllable cost (TOTEX) as an input. In this case, the company will remain indifferent to the mix of inputs, provided that each company is able to deliver its required outputs at lowest total cost. The threat that investments may be rejected, or partially disallowed, in the process would provide an incentive to the regulated company to only undertake efficient investment. Such an incentive is necessary because the regulated company is likely to hold better information than the regulator about the prospective efficiency of a proposed investment. Therefore, by making the company to accept the consequences of its investment decisions, the probability that inefficient investment will take place is weakened.

On the other hand, the regulatory threat that investments could be disallowed, and then excluded from the regulatory asset base, could discourage regulated companies to implement even good investment projects. Also, there may be capital expenditure that is planned and conducted in good faith that eventually proves “imprudent” on an ex-post basis. Obviously, the straight application of TOTEX economic benchmarking may completely disregard the prospective needs of network investments and may put some hazards on reliability.

The regulatory cap regime should be structured in such a way that the companies earn sufficient revenue to cover their efficient OPEX and CAPEX. The objective of encouraging investment in the electricity networks will require investors to be provided with an assurance that they will earn a reasonable (risk-adjusted) return on their investment. This is in particular

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[53] Additionally, these streams may be finally smoothed out to produce annual revenues/prices that change proportionally. The X factor is a solution of the financial equivalence equation and integrates the implied efficiency increase in the OPEX and CAPEX projections plus the smoothing-out over the regulatory period. This approach is well-known, and is used in the UK and Australia.

relevant for the ERRA countries with on-going or planned privatisation strategies. Moreover, in most of the ERRA country members, the energy industry suffered from severe under-investment in the past. The results are poor quality of supply and high network losses. There is need for significant investments in the future, in order to catch up with the development of the network infrastructure and enhance reliability of supply.

Finally, measuring CAPEX provides just an “instantaneous” (at a certain time point) efficiency assessment. A number of issues, resulting form the long-term nature of CAPEX, should be solved before the regulator decides to apply a TOTEX method. Notable examples of challenges to ensure CAPEX comparability relate to differences in depreciation policy, capitalization policy, and network asset age of the regulated companies.

Based on the arguments provided above, we feel that the application of benchmarking analysis on controllable OPEX is a reasonable solution for the ERRA member countries.

8.3.3.1 Data availability and data quality

Data quality is particularly relevant when individual inefficiency (and X factor) is computed on the basis of comparative efficiency analysis. In this case, the inefficiency of one company is set on the basis of its costs and performance relative to other companies. If data for one of these companies is wrong, this may potentially impact the efficiency position of other companies. **Therefore, regulators should ensure a high quality of the collected data before start conducting benchmarking analysis.**

Irrespective of how the collected information is used, regulators should be entitled by means of legislation to ask regulated entities for information without any confidentiality barriers – given reasonable exceptions (for instance, proven commercially sensitive information that should be disclosed to the regulator but not published otherwise).

Since in most countries of the ERRA region, no large numbers of regional distribution network operators exist, it is difficult, if not impossible, to run effective domestic benchmarking models. This structural problem can be solved by extending the sample internationally, i.e. benchmarking comparable companies in the region. **We recommend ERRA regulators to enhance their cooperation towards the establishment of regional data pools or one common ERRA data pool. The data pool should contain and regularly update relevant data that may be used for international benchmarking. All data definitions should be carefully agreed upon before starting with any work on the pool’s establishment.**

8.3.3.2 The X factor

The X factor should reflect: the individual inefficiency levels of regulated companies (resulting from benchmarking analysis) and the frontier shift, equivalent for all regulated companies in the sample. Regulators should take into account the limitations of benchmarking. **Efficiency scores should be considered as an indication, rather than a confirmation, of inefficiency. Given the large degree of uncertainty in the results of a benchmarking study, its outcomes should be used with a pinch of salt. Therefore, benchmarking results should not be converted mechanically into X factors, but should rather be mediated by careful qualitative consideration of the following: realistic and affordable efficiency improvement potentials/paths, time needed to achieve these efficiency improvements, and general price reform trends going on in any specific country.**

APPENDIX 1: Technical Considerations on Parametric Techniques

Econometrics nowadays provides the standard of proof across the full range of applied microeconomics, ranging from household spending to investment by utilities and the organisation of industries, labour markets, and the effects of public policy.

For instance, if we are analysing the relationship between wages and work experience, we must collect economic data and look for positive correlation between pay and years of experience. One problem is, however, omitted variable bias (OVB). Missing information interferes with the estimated correlation between variables. Another problem is reverse causality – in our example, the idea that wages may affect experience. For instance, employees who receive higher wages are more likely to stay with the company, and thus gain more experience. If so, any conclusions drawn from the estimated correlation might be misleading. A remedy might be to work with a "proxy" for experience, choosing a variable that is unaffected by wages: age, for example. Age, in this case, is an “instrumental” variable.

The econometric model underlying the linear regression estimation option is the classical “linear regression” model. This model assumes that the relationship between the dependent variable and the K regressors on the right-hand side of the estimated equation is a linear one.

There are, however, many assumptions related to the disturbance (or “error”) terms to underpin this straight linear relationship. They are:

- Zero mean assumption: the disturbances have a zero mean and a constant conditional variance across all of the observations in the sample.
- Orthogonality assumption: the disturbances and the regressors are uncorrelated (i.e. there is no systematic element in the disturbances that may represent a variable directly correlated with any of the explicit regressors).
- Normality assumption: disturbances are normally distributed.

In using econometrics, we must pay attention to the tools for our analysis. For instance, the T-tests on individual regression coefficients should be carried out with care, particularly when regressors exhibit a certain degree of co-linearity. It is a good practice to combine the T-tests on individual coefficients with the F-test of joint restrictions on the coefficients, i.e. on the regression as a whole. It is important that the results of the individual T-tests (also known as separately-induced tests) and the joint F-test are not in conflict.

Important tests that are used in simple equation options are Durbin-Watson Tests for serial correlation, the Lagrange multiplier Test and Bera-Jarque's Test (for normality testing) and Chow's Test for structural breaks in time series analysis. In multiple equation models, one can use the estimation of SURE (seemingly unrelated regression equations), "impulse-response analysis", and co-integration.

Heteroscedasticity Tests

These refer to the possibility that one of the key requirements of OLS regression is not met: the variance of errors is no more constant across all observations. If the errors have constant variance, they are called “homoscedastic” and OLS regression gives, other things being equal, best (minimum variance) linear unbiased estimators in the form of OLS estimated coefficients (BLUE property). Residual plots can help assess this assumption, but more sophisticated statistical corrections exist to prove it with some degree of confidence. Standard estimation methods become inefficient when the errors are heteroscedastic, i.e. when they have non-constant variance.

There are two generally accepted tests for heteroscedasticity of the errors: White's test and the modified Breusch-Pagan (Lagrange Multipliers) test. Both White's test and the Breusch-Pagan (LM) one are based on the residuals of the fitted model. For systems of equations, these tests are computed separately for the residuals of each equation. The residuals of an auxiliary estimation are used to investigate the heteroscedasticity of the “true” disturbances.

The White testing option tests the null hypothesis that OLS residuals for each of the observations in one’s sample share the same and one variance – with no deviations.

White's test and correction strategy is general because it makes no assumptions about the form, or structure, of the heteroscedasticity. Because of its generality, White's test – when explicitly performed - may also identify more general model specification problems other than heteroscedasticity.

Apart from correcting standard errors by means of the White method, sometimes it is good econometric practice to perform a supplementary Lagrange Multiplier (Breusch-Pagan/LM) test for heteroscedasticity.

Ommited Variable Bias

Omitted variable bias occurs when an independent variable that is:

- relevant to explaining the dependent variable; and
- correlated with at least one of the inserted independent variables

is unfortunately omitted from the regression. For example, consider the following regression model:

*Output = Alpha + Beta * Input + error(s).*

Upon running the regression, we find the coefficient Beta to be positive and statistically significant. The result seems to support the existence of a definitely positive relationship between input and output. However, the magnitude of the effect might be either exaggerated or depressed depending on whether the model is effective in capturing what the “real” degree of this relationship is.

For instance, there may be an omitted variable that is relevant to explaining output and is correlated with input. This variable can be an environmental effect. Consider now the following regression model in which we have added the variable “external”.

*Output = Alpha + Beta * Input + Gamma * External + error(s).*

Upon running the regression, we find that the new Beta is lower than the old one. The omission of a relevant explanatory factor had then resulted in omitted variable bias on input – in this case, an exaggeration. Specifically, the old Beta was biased upwards or is higher than its “true” value.

Which way can the bias be? It can be either way, as the bias depends on the sign of Gamma and on the nature of the correlation between the input variable and any other environmental variable being inserted.

In many regression models the control for omitted variable bias is done by adopting a “general-to-specific” estimation methodology that included all possibly available information, and tested the model down by gradually eliminating unnecessarily included variables. The opposite strategy (specific to general) is sometimes less effective in tackling omitted variable bias as it is not always possible, under that strategy, to determine in which way a general model is constructed – by gradually including new variables – so that the bias is gradually eliminated rather than simply shifted in sign.

APPENDIX 2
Formulation of the Tornqvist Index

Generalities

The productivity of a company is measured by the quantity of output produced per unit of input. In the case of a company producing single-output and single-input this would simply the ratio of its output and input quantities. Thus, if in period 0, a company produces output yo with input xo, its productivity is:

$$\Pi_o = \frac{y_o}{x_o}.$$

Similarly, in period 1, when output y_1 is produced from input x_1, the productivity ratio is

$$\Pi_1 = \frac{y_1}{x_1}.$$

The productivity index which measures the productivity change between the two periods (using period 0 as a base) is:

$$\pi_1 = \frac{\Pi_1}{\Pi_0} = \frac{y_1/x_1}{y_0/x_0} = \frac{y_1/y_0}{x_1/x_0}.$$

The rate of productivity change is the ratio of the changes for the output and input quantities respectively defined by simple division of the relevant period values. When multiple inputs and/or multiple outputs are involved, one should replace the simple ratios of the output and input quantities in the equation above by quantity indexes of output and input. In this case, the index of multi-factor productivity is:

$$\pi_1 = \frac{\Pi_1}{\Pi_0} = \frac{Q_y}{Q_x},$$

where Q_y and Q_x are, respectively, output and input quantity indexes of the utility in period 1 with period 0 as the base.

The Tornquist TFP Index

One of the most popular quantity index number is the Tornquist index measured by a weighted geometric average of the relative quantity changes from the two periods. Let's study the output quantity index first. Suppose that m outputs are involved. The output vectors produced in periods 0 and 1 are, respectively, $y^0=(y_1^0,y_2^0,\ldots,y_m^0)$ and $y^1=(y_1^1,y_2^1,\ldots,y_m^1)$. The corresponding output price vectors are $p^0=(p_1^0,p_2^0,\ldots,p_m^0)$ and $p^1=(p_1^1,p_2^1,\ldots,p_m^1)$ respectively. Then, the Tornqvist output quantity index is:

$$TQ_y=\left(\frac{y_1^{\ 1}}{y_1^{\ 0}}\right)^{v1}\left(\frac{y_2^{\ 1}}{y_2^{\ 0}}\right)^{v2}\cdots\left(\frac{y_m^{\ 1}}{y_m^{\ 0}}\right)^{vm};\sum_1^m v_j=1.$$

where

$$v_j=\frac{p_j y_j}{\sum_1^m p_k y_k}$$

is the share of output *j* in the total value of the output bundle. The share of the individual outputs can change from period to period. In practical applications, for v_j, one uses the geometric average of $v_j^{\ 0}$ and $v_j^{\ 1}$, where:

$$v_j^{\ 0}=\frac{p_j^{\ 0}y_j^{\ 0}}{\sum_1^m p_k^{\ 0}y_k^{\ 0}} \quad \text{and} \quad v_j^{\ 1}=\frac{p_j^{\ 1}y_j^{\ 1}}{\sum_1^m p_k^{\ 1}y_k^{\ 1}}.$$

Similarly, let the input vectors in the two periods be $x^0=(x_1^{\ 0},x_2^{\ 0},\cdots,x_n^{\ 0})$ and $x^1=(x_1^{\ 1},x_2^{\ 1},\cdots,x_n^{\ 1})$. The corresponding input price vectors are $w^0=(w_1^{\ 0},w_2^{\ 0},\cdots,w_n^{\ 0})$ and $w^1=(w_1^{\ 1},w_2^{\ 1},\cdots,w_n^{\ 1})$.

Then, the Tornqvist input quantity index is

$$TQ_x = \left(\frac{x_1^1}{x_1^0}\right)^{s_1}\left(\frac{x_2^1}{x_2^0}\right)^{s_2}\cdots\left(\frac{x_n^1}{x_n^0}\right)^{s_n};\sum_1^n s_j = 1$$

Where

$$s_j = \frac{w_j x_j}{\sum_1^n w_k x_k}$$

is the share of input *j* in the total cost of the input bundle. Again, in practice, one uses the geometric average of the cost share of any input in the two periods. The Tornqvist productivity index is the ratio of the Tornquist output and input quantity indexes. Thus,

$$\pi_{TQ} = \frac{TQ_y}{TQ_x}$$

When TQ y >TQ x, output in period 1 has grown faster (or declined slower) than input as a result of which productivity has increased in period 1 compared to what it was in period 0. Obviously, the Tornqvist productivity index can be measured without any knowledge of the underlying technology so long as data are available for the input and output quantities, as well as the shares of the individual inputs and outputs in total cost and total revenue, respectively.

APPENDIX 3
Formulation of the Malmquist Index

The Malmquist TFP index measures the TFP change between two data points by calculating the ratio of the distances of each data point relative to a common technology. On advantage of the Malmquist TFP is that is that the TFP index can be decomposed into two components: and relative efficiency change (firms getting closer to the frontier) and technical change (frontier shift).

The Malmquist index is defined using distance functions. Distance functions can be used to describe a multi-input and multi-output production technology. Input and output distance functions may be defined. An input distance function characterises the production technology by looking at a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of the output vector, given an input vector.

The Malmquist (input-orientated) TFP change index between period t (the base period) and period t+1 is given by

$$\mathrm{M}_i^{t,t+1} = \left(\frac{D_i^t\left(x^{t+1}, y^{t+1}\right)}{D_i^t\left(x^t, y^t\right)} \cdot \frac{D_i^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_i^{t+1}\left(x^t, y^t\right)} \right)^{1/2}$$

where the notation $Di^t(x^{t+1}, y^{t+1})$ represents the distance from the period t+1 observation to the period t technology. A value of Mi greater than one will indicate positive TFP growth from period t to period t+1 while a value less than one indicates a TFP decline. Note that equation is, in fact, the geometric mean of two TFP indices. The first is evaluated with respect to period t technology and the second with respect to period t+1 technology. An equivalent way of writing this productivity index is:

$$\mathrm{M}_i^{t,t+1} = \frac{D_i^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_i^t\left(x^t, y^t\right)} \cdot \left(\frac{D_i^t\left(x^{t+1}, y^{t+1}\right)}{D_i^{t+1}\left(x^{t+1}, y^{t+1}\right)} \cdot \frac{D_i^t\left(x^t, y^t\right)}{D_i^{t+1}\left(x^t, y^t\right)} \right)^{1/2}$$

The first term is the change in efficiency between period t and t+1 (relative efficiency change, REC) while the second term measures the shift in the frontier (frontier shift, FS). The decomposition of the Malmquist total factor productivity (TFP) index into a portion due to technological and efficiency change is based on a simple algebraic manipulation of the Malmquist output oriented TFP index and is discussed in Färe et al. (1994) using non-parametric methods.

$$REC = \frac{D_i^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_i^t\left(x^t, y^t\right)}$$

$$FS = \left(\frac{D_i^t\left(x^{t+1}, y^{t+1}\right)}{D_i^{t+1}\left(x^{t+1}, y^{t+1}\right)} \cdot \frac{D_i^t\left(x^t, y^t\right)}{D_i^{t+1}\left(x^t, y^t\right)} \right)^{1/2}$$

The decomposition is illustrated in the figure below which implies a technology with constant returns to scale using single input/single output.

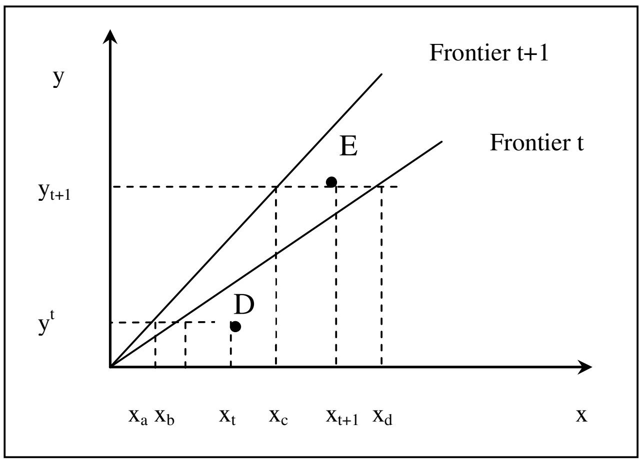

Figure 15 *Illustration of Frontier Shift*

The company produces at the points D and E in periods t and t+1, respectively. In each period the utility is operating below the technology for that period. Hence, there is technical inefficiency in both periods. Using the mathematical equations above we can obtain:

$$REC = \frac{x_c / x_{t+1}}{x_b / x_t}$$ and

$$FS = \left(\frac{x_d / x_{t+1}}{x_c / x_{t+1}} . \frac{x_b / x_t}{x_a / x_t} \right)^{1/2}$$

In an empirical application, the four distance measures which appear in the equations must be calculated for each utility in each pair of adjacent time periods (t, t+1). This can be done using DEA mathematical programming techniques with the availability of panel data and running one linear program (distance function minimisation) for each unit in the sample, and for each period in turn.

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