MUNICIPAL ENERGY REFORM PROJECT IN UKRAINE (MERP)

REVIEW ON METHODS OF ECONOMIC ANALYSIS AND UTILITY EFFICIENCY CALCULATION IN WATER & WASTEWATER SECTOR IN EU COUNTRIES

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REPORT

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Methods used of economic analysis for water and sewerage utilities' efficiency calculation

1. The Report provides overview of methods practically used by water sector regulators in European countries. First, Report starts with short presenting of practical state of play, and then continues with description of the methods that are used and that might be used for the purpose, since the theoretical variety of methods is greater than the practical variety for the date.
2. The European regulators for efficiency factor determination, directly or indirectly, in the context of incentive based regulatory schemas, use the methods of economic analysis as presented below.
3. **Bulgaria, KEVR**: data envelope analysis DEA method, for entities clustered into 4 clusters[1]. The new system is to be implemented fully, as announced by KEVR, since new regulatory period 2017 – since there was decision for prolongation of the previous regulatory period for the second time. It is to be noticed, that KEVR makes all the data on indicators for every individual operator public in the form of Report, bus also, in the form of excel sheets for every operator every indicator over years; and this practice of publicity for entities might be incentivizing as well.
4. **Denmark, Konkurence-og-Forbrugerstyrelsen**: data envelope analysis DEA method is used to benchmark OPEX, under price-cap regime[2]. In Denmark, there are used two types of costs with this regard. To determine frontier entities in the market, the factual OPEX of recent period is used (for eg. Y2011 factual for planned Y2013); to determine the actual efficiency potential of each entity, adjusted OPEX from the base years (Y2003-2005) is used. DEA is made in two stages; the

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[1] The clusters are derived according composite index called "Specific Conditions" (SC). This SC index is estimated as the formula blow provides:

- Population served (by entity i, as % of total population served in market), weight given 0.45,
- Revenue from water and sewerage (by entity i, as % of total revenue of market), weight given 0.35,
- Amount of water supplied to the system (by entity i, as % of total quantity of market), weight given 0.20

$$SC_i = \frac{N_i}{N} * 0.45 + \frac{R_i}{R} * 0.35 + \frac{Q_i}{Q} * 0.20$$

Cluster ranges are established as follows:
Large entities' cluster, when $SC_i > 3\%$
Medium entities' cluster, when $3\% \geq SC_i > 0.95\%$
Small entities' cluster, when $0.95\% \geq SC_i > 0.20\%$
Micro entities' cluster, when $0.20\% \geq SC_i$

[2] Introduced by 2011.

second DEA is performed after taking out the most efficient companies out of the analysis[3]. The second DEA is used to estimate efficiency potentials. Additionally, the SFA analysis results are used to make a general correction before performing the final DEA to obtain the corrected efficiency potentials (up to 20%-25%). In addition to that, the regulator perceives that entities are able to achieve 25% of their efficiency potential in 1 year time. Minor comment regarding profits: in Denmark, profits cannot be distributed but have to be reinvested in the sector, even when the profits is achieved through efficiency enhancement.

5. **England and Wales, OfWat** : to increase comparability among benchmarked entities, OfWat has introduced separation between water and wastewater entities, and between retail and wholesale businesses either. OfWat benchmarks TOTEX, uses regression analysis (method COLS) and setts price limits for entities as if those entities are in the top quarter for the most efficient entities over the last five years. In **Scotland**, WaterCommision uses the model of OfWat to determine operating costs efficiency potential for Scottish Water.
6. In addition, OfWat uses combined sunshine-financial approach to service performance under SIM mechanism (Service Incentive Mechanism). OfWat publishes the performance indicators of entities, to reward good customer service performance by reputational mean; by price review approach the entities are penalized either rewarded for their performance under SIM mechanism.
7. In addition, OfWat uses sunshine approach regulation: towards abstraction at low flows from environmentally sensitive sites, so called AIM (abstraction incentive mechanism), which means encouraging entities to reduce abstraction at low flows at environmentally-sensitive sites compared to its baseline historic level. The AIM mechanism in future will be turned to specified rewards (and penalties) in price limits, however, for the 2015-2020 period is completely sunshine regulation, which is founded on reputational basis.
8. **Ireland, CER**: In Ireland, Irish Water is benchmarked against all UK entities and Northern Ireland Water - comparators, which have a range of network demographic characteristics, some more and some less similar to Ireland. Pooled ordinary least squares (POLS) model, Random Effect (RE) and Stochastic Frontier Analysis (SFA) are used in Ireland to assess comparative efficiency potential for Irish Water.

[3] Due to consideration, that voluntarily performed works (volunteer workforce), as is a kind of practice in DK for small private companies, and therefore possibly lower service levels in terms of shorter opening hours for telephone inquiries, might lead to lower operating costs. Thus, the Water Department has decided that the efficient frontier cannot consist of the private water companies.

9. **Italy, AEEG**: the revenue cap[4] has coefficient K, which is practically used as the component limiting growth of tariffs over RPI level to max 5% (or 7.5% in certain cases), and additionally adjusted by half of profits gained in commercial activities by the entity in question (the commercial profits thus way are obliged to be used for regulated activities' cost/investment needs coverage). This upper limit works in inverse direction as efficiency factor.
10. **Lithuania, VEKK**: comparison of entity's indicator against average[5] indicator at relevant cluster or relevant regulatory standard is performed. Cost efficiency trend is ensured while using the more efficient value for regulated revenue / tariff establishment. The efficiency factor X is established and included into regulated revenue indirectly. The formula for efficient cost limit establishment is as provided below:

    For losses and insulation, %, costs to be included into regulated revenue:

    $$C_{plan\ period}^{efficient} = \mathbf{min}\{C_{reported\ period}^{factual}; C_{plan\ period}^{regulatory\ standard}\}$$

    For other indicators, cost to be included into regulated revenue:

    $$C_{plan\ period}^{efficient} = \min\{p_{plan\ period}^{entity\ plan} * q_{plan\ period}^{entity\ plan}; \ p_{reported\ period}^{cluster\ AVG} * q_{reported\ period}^{cluster\ AVG}\}$$

    It is to be noticed, that in addition to efficient cost establishment, there is extra efficiency target for yearly price changes under $(CPI - X)$ model, and in Lithuania standard $X = \frac{1}{2} * CPI$ with general condition to be respected$(CPI - X) \leq 3\%$.

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[4] Revenue cap, before the new legislation, has been installed in Italy since 20 years ago; however, the way of working the regulation was not price cap, but rather cost plus, since the price for was calculated not according to actual costs, but according to planned costs, and if actual costs were different form the planned one, the operator asked for adjustments; the regulator asked for efficiency improvements in the case actual costs were higher than the planed costs by +30%.
The "new price cap" regulation, assigned to AEEG by 2012, has the following elements: CAPEX, Component for supporting specific new investment, OPEX, Component for coverage of environmental and resource costs, Component to balance the revenues limit for the operator in the previous years. The tariff formula in Italy works as follows:

$\frac{\partial_t}{\partial_{t-1}} \leq (1 + RPI + K)$, and $K = 5\%$, when ordinary flow is sufficient to finance investment,

$\frac{\partial_t}{\partial_{t-1}} \leq [1 + RPI + (1 + \gamma) * K]$, and $\gamma = 0.5$, when ordinary flow is not sufficient to finance investment.

[5] Geometrical average is used, and prior two extreme values (one max value and one min value) are eliminated from the average estimation.

11. **<u>Portugal, ERSAR[6]:</u>** performance indicators are assessed in qualitative way, scoring performance for every entity every indicator as good, average and low performance for every operator. Efficiency is derived via publicity and internal incentives of operators. The type of regulation used in Portugal is called sunshine regulation. Similarly, sunshine regulation[7] is used in **<u>Netherlands</u>**, where benchmarking is coordinated by association of industry VEWIN, and observers of the system report significant increases in efficiency of the industry. **<u>Finland</u>** – another country with voluntary benchmarking, conducted for years, by industry associates FIWA, and used a managerial tool for efficiency.
12. The information provided below is more of description nature as on variety of different methods available. The variety used in infrastructures' regulation to establish efficiency potential is rather wider than the variety observed in water and sewerage sector regulation in Europe, as presented above. From the other hand, it looks like water & wastewater regulatory efforts over last 3-4 years have got some dynamics towards harmonization over Europe, and one of incentives for the dynamic has been *inter alia* the EU Water Directive. The availability of monitored water & sewerage business data through years, in some European countries, which in many cases started as voluntary efforts on national level, provide a good basis for efficiency factor determination in the context of incentive based regulation.

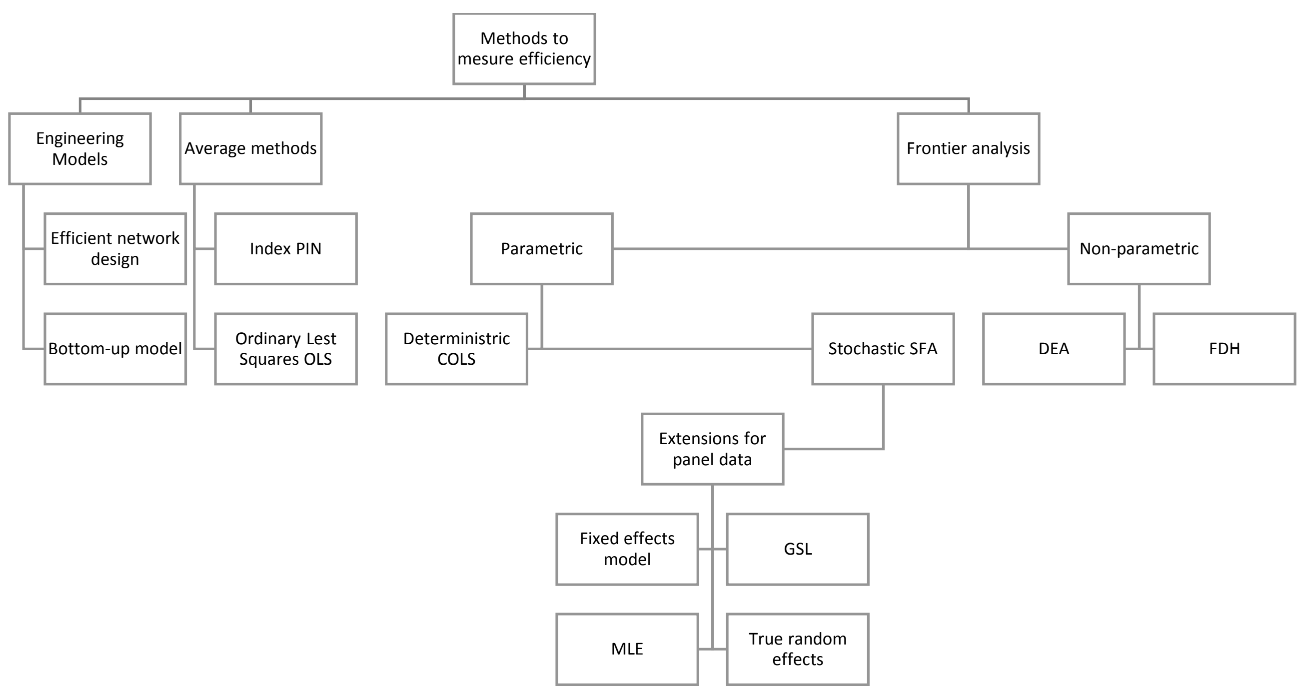
[6] Cost plus revenue regulation is used; discussions towards revenue cap. WACC is established and used. Regulatory period – 1 year.
[7] "naming-faming-shaming"

Methods of economic analysis for efficiency

13. RPI-X regulation to a major part is aimed at improving efficiency through incentives. Usage of benchmarking implies measuring an entity's efficiency and rewarding accordingly.
14. The value of X is generally based on the regulator's assessment of the potential for productivity growth in the regulated entity. Estimating X is a complex matter - it is supposed to reflect the extent to which the regulated industry can improve its productivity faster than the rest of the economy in which it is operating, accounting for differences in the evolution of the input prices in the regulated industry compared with the input prices in the rest of the economy. Reasonable estimates or aggregate productivity gains are generally available; however, information at the sector-level is often incomplete; information on entity's level is due to be established by regulating body.
15. As for definition of X factor, the approaches most commonly in practice are used:
    - X-factor is set equal to the annual expected or target growth rate of the total factor productivity (TFP) in the entire sector. As for drawback, it shall be mentioned that this approach might induce undesired incentive effects – relatively inefficient entities might, as the result of regulation, acquire higher benefits than those with already higher efficiencies in operations, which cannot further improve their productivity significantly;
    - X-factors is set equal to the annual target change in productive efficiency for each individual entity. The regulator sets differentiated price caps based on the entity's efficiency performance estimated from a benchmarking analysis, and this implies measuring the particular entity's productive efficiency against a reference performance. This approach does not account for TFP growth;
    - To avoid drawback of both "pure" alternatives named above, a third approach might be employed. X-factor is set as a sum of decomposed two TFP growth components: one component is growth due to technical progress in the industry (common for the entire sector), and the other component is growth related to the entity-specific efficiency improvements (individual for the entity in question). This approach tailors the price caps to individual entities' performance, and this is the main advantage of this approach to X-factor determination model.

16. Here it worth mentioning that while considering the unified X factor for the entire industry, several conditions must be in place: (i) all the regulated services are subject to cap regulation; (ii) no major structural changes (for eg. competition) are anticipated in regulated industry; (iiI) the rate of price inflation outside the regulated sector is not affected by the pricing decisions of the regulated entity; (iv) the economy outside the regulated sector is competitive.
17. The reliability of efficiency estimate is crucial for an effective implementation of incentive mechanisms, especially at the existence of variety of legitimate benchmarking models, which produce different results. This implies that the choice of benchmarking model might have important effects on the financial situation of the regulated entities.
18. The estimation of efficiency can be performed using a wide variety of models. The Figure 1 below represents the major examples of the efficiency measurement methods' family.
19. The benchmarking analysis methods can be classified as either average or frontier-oriented. The former compare firms against some average level of performance, while the latter measures their performance against the efficient frontier or best practice. It is assumed that the average average-based approaches are better suited to introduce competition between homogeneous entities, while frontier methods are used as instruments to close performance gaps.

Figure 1. **Efficiency measurement methods**



20. **Price-based Index Numbers PIN**: traditional number index approach to productivity measurement. Prices are used as the weights, Tornqvist or Fisher formulas are employed. Quantity and price data on inputs and outputs for two or more entities or time periods are needed. Advantages – can be performed on as little as two observations; it is reproducible and transparent; captures allocative efficiency. Drawbacks – price information is needed; cannot decomposed productivity measure into components. The general formula is presented below (when having two time periods t and (t-1), with Y – output, m - variety of outputs, a - weight for output m, X – input, n – variety of inputs, b – weight for input n):

$$\frac{FP_t}{FP_{t-1}} = \left[\frac{\sum a_m * Y_{m,t} / \sum b_n * X_{n,t}}{\sum a_m * Y_{m,t-1} / \sum b_n * X_{n,t-1}} \right]$$

21. **Non-parametric frontier analysis methods' group** uses linear programming to determine an entity's efficiency frontier. The cost frontier is a deterministic function of the observed variables and no specific functional form is imposed. Non-parametric approaches are generally easier to estimate and can be implemented on smaller datasets.
22. **Data Envelope Analysis DEA**: non-parametric method, requiring comparatively large data set. DEA is a non-parametric method and uses piecewise linear programming to calculate (rather than estimate) the efficient or best-practice frontier in a given set of entities. The entities that make up the frontier envelop the less efficient entities and the relative efficiency is calculated in terms of scores on a scale of 0 to 1, with the frontier entities receiving a score of 1. DEA can calculate the allocative and technical efficiency, and the latter can be decomposed into scale, congestion, and pure technical inefficiency. DEA models can be input and output oriented. Output-oriented DEA models maximize output for a given quantity of input factors; input-oriented models minimize input factors required for a given level of output. DEA models can be specified as constant returns to scale (CRS) or variable returns to scale (VRS).
23. Put it shortly, the efficient frontier is the benchmark against which the relative performance of the entity is measured. Under a certain set of entities, all of them should be able to operate at an optimal efficiency level which is determined by the efficient entities in the set. These efficient entities are referred as the "peer firms" and determine the efficiency frontier. The entities that form the efficient frontier use minimum quantity of inputs to produce the fixed quantity of

outputs, or v.v. using fixed quantity of inputs produce maximum quantity of output. The distance to the efficiency frontier provides a measure for the efficiency or its lack thereof. The Figure of DEA model is presented in Figure A-1 (Annex 1).

24. Advantage of DEA is that is that inefficient entities are compared to actual entities rather than to some statistical measure. In addition, DEA is rather a simple method to use since DEA does not require specification of a cost or production function. DEA is able to accommodate a multiplicity of inputs and outputs. DEA takes into consideration returns to scale in calculating efficiency, allowing for the concept of increasing or decreasing efficiency based on size and output levels.
25. Among shortcomings of DEA, it worth mentioning that the efficiency scores tend to be sensitive to the choice of input and output variables, and the method does not allow for stochastic factors and measurement errors. Further, as more variables are included in the models, the number of entities on the frontier (efficient entities) increases, so it is important to examine the sensitivity of the efficiency scores and rank order of the entities to model specification.
26. **Free Disposal Hull FDH**: non-parametric method. The model originally was designed as an alternative to data envelopment analysis model, however, still allowing the measurement of the relative distance that an individual entity lies away from this estimated frontier. The frontier defines the relationship between inputs and outputs by depicting graphically the maximum outputs obtainable from the given inputs. FDH assumes it does not have a particular functional form for the boundary and ignores measurement error. FDH uses mathematical programming techniques to envelop the data as tightly as possible, subject to certain production assumptions, which are maintained within the mathematical programming context. Using FDH for any given level of outputs remains feasible if any of the inputs is increased, whereas the latter means that with given inputs it is always possible to reduce or maximize outputs. The FDH methodology is considered as suitable to detect the most obvious cases of entities' inefficiency as this technique is very assertive regarding the measurement of entities' inefficiency. To each entity declared FDH inefficient, it is possible to find at least one entity in the sample, which presents a superior performance. The Figure of FDH model is presented in Figure A-2 (Annex 1).
27. **Parametric frontier analysis methods** assume a parametric form for the cost/production frontier. The parametric approach is subdivided into deterministic and stochastic models. Deterministic models envelope all the observations, identifying the distance between the observed production and the maximum production, defined by the frontier and the available technology, as technical inefficiency. On the other hand, stochastic approaches permit to distinguish between technical

efficiency and statistical noise. The measurement of productive efficiency by means of parametric techniques requires the specification of a particular frontier function, namely, cost function. The output produced by entities under regulated environment, as well as the prices they pay for inputs in competitive markets, are considered to be exogenous.

28. **Deterministic Corrected Ordinary Least Squares COLS**: parametric regression method. COLS is a stochastic method used to impart some statistical properties to the frontier; the model's parameters (excluding the constant term) can be consistently estimated using Ordinary Least Squares (OLS). To estimate the constant, the OLS intercept is shifted upward until only one or more observations lie on the frontier and all others lie below it. This method ignores the possibility of exogenous shocks, measurement error, and statistical noise since all deviations from the frontier are attributed to the one-sided error component that captures entity's inefficiency.
29. At applying the COLS method, an equation which describes the relationships between a dependent variable (y, which here represents an entity's costs) and several explanatory variables (x1, x2, x3, etc., representing the entity's operating conditions and demand), is necessary to determine, and at the first step it is determined as Ordinary Least Squares OLS regression function, with the intercept a, and the gradient, b. Given the information available, the OLS line defines the costs that one would expect an entity to incur, given its output. Some entities have higher costs (above the line) and some have lower costs (below the line). After determining the most efficient entity in the set, then the regression line is moved until no entity lies below the line. This corrected line has the same gradient as the OLS line (b), but it has the changed intercept (a). COLS is an extreme version of the regression technique, based on the presumption that the "lowest data point" defines efficient costs rather than simply being an outlier reflecting data measurement problems or other extraneous factors, and on the assumption that the estimated OLS gradient is still valid at the frontier. The Figure of OLS and COLS models is presented in Figure A-3 (Annex 1).
30. OLS reveals information about cost structures and distinguishes between different variables' roles in affecting output. Coefficients are interpreted as input influence to output. However, desired reliability calls for usage of large data sets which might not be available every time; on the other hand, statistical noise is not eliminated. In the case of COLS, the adjustment turns the OLS into a "frontier" approach, still preserving advantage of good explanation between inputs and outputs. COLS is especially sensitive to outliers, since the "best" performer along any dimension serves as the anchor for the estimate.

31. **Pooled ordinary least squares (POLS)**: estimates "Efficient Expenditure" or the "cost function" by estimating the average relationship between expenditure and cost drivers. To do this estimation, POLS treats all data observations as though they were from separate entities, even if the data represents the same entities over a period of time. This leads to an estimate of average entity expenditure, as well as a "residual" – the difference between this estimate of average expenditure and the entity's actual expenditure. The method then calculates efficient expenditure post-modelling. This calculation is done by assuming that: (a) the most efficient entity is the entity that has the smallest (most negative) residual; (b) the most efficient entity, identified in (a), has efficient expenditure equal to its actual expenditure; a percentage adjustment is calculated that is used to adjust the estimated average expenditure from POLS down to its actual expenditure; (c) The adjustment calculated in (b) is used to adjust all the entities' estimated average cost to identify their efficient level of expenditure. Using POLS, it is difficult to distinguish between inefficient expenditure and random noise listed above, therefore some proportion must be adopted to split the two. For example, the remaining difference between the calculated efficient expenditure and actual expenditure is assumed to be X% random noise, which allows for a split to determine inefficient expenditure.
32. **Modified Ordinary Least Squares MOLS**: alternative method (extension of COLS) is based on the argument, that COLS is inadequate if the error term follows a one-sided distribution such as exponential or half-normal. MOLS consists of correcting the intercept with the expected value of the error term and adopting OLS to get a consistent estimate. However, with MOLS technique the estimates can take on values which have no statistical meaning. It does not ensure that all units are bounded from above / below by estimated production / cost frontier. The estimators are efficient but not consistent and consistency is the greatest point of concern for MOLS.
33. **Random effects (RE)**: corrects the treatment of all data observations as separate entities, by treating data as a "panel" – data which represents a numbers of entities over a time period. As a result, the estimation of the average relationship between expenditure and cost drivers is likely more accurate. However, RE cannot distinguish between inefficient expenditure and random noise.
34. **Stochastic Frontier Analysis SFA**: parametric method. SFA produces efficiency estimates or efficiency scores of individual entities, attempting to determine an efficient frontier eliminating the statistical noise due to data errors, omitted variables etc. Visualization is presented in Figure A-4, Annex 1. The most widely used stochastic frontier models include the stochastic production

frontier model, stochastic cost frontier model, and stochastic distance function model. Stochastic production frontier model will request data from inputs and outputs from array of entities over number of years. Stochastic long-term cost frontier model will require data for total costs, input prices, output quantities. Stochastic short-term cost frontier model will require data on variable costs, variable input prices, fixed input quantities, output quantities.

35. Advantages of the SFA include ability to detect inefficiency and random factors separately; standard statistical tests can be used to test hypotheses on model specification and significance of the variables included on the model; ability to deal with multiple outputs. Shortcomings of SFA are the following: the separation of noise and inefficiency relies on strong assumptions on the distribution of the error term; there is a need of functional form and production technology specification; requirement for sufficient data which might not be available for regulator at particular moment.

36. As it was mentioned above, the choice of a particular method to estimate efficiency has important consequences since the estimated efficiency scores are directly used to reward/punish individual entities through regulatory schemes, for example revenue-cap / price-cap formulas. However, the single clear criteria for the choice of the method is non-existent. In research community, it is assumed that the results of analysis are valid if they are independently obtained from several models, meaning in the context of the Report, that to obtain valid efficient score, first, several methods of efficiency measurement shall be employed independently by the regulator, and second, all they must produce comparable and consistent result.

37. Some authors[8] propose using extensions for panel data to overcome the shortcoming mentioned above and be used in regulatory practical work. The extension for panel data provide, first, a better control for the firm- or network-specific unobserved heterogeneity, which is a source of discrepancy across different benchmarking methods, and second, the moving from point estimates for efficiencies to confidence intervals for predicted costs.

38. **Network design models**: Network models have a mixed engineering and economic/mathematical background and differ from conventional benchmarking approach to efficiency in two main ways:
    - Firstly, network models are based on the comparison of the entity's performance against that of an artificially constructed "optimal" entity. This optimal entity (the benchmark) is thus not a real existing one but rather follows from the rules and procedures embedded within the

[8] Farsi, M., Fetz, A., Filippini, M. 2007.

network model tool. Network models thus effectively bypass the need for a benchmarking sample and can in principle be applied to the case of a single entity;

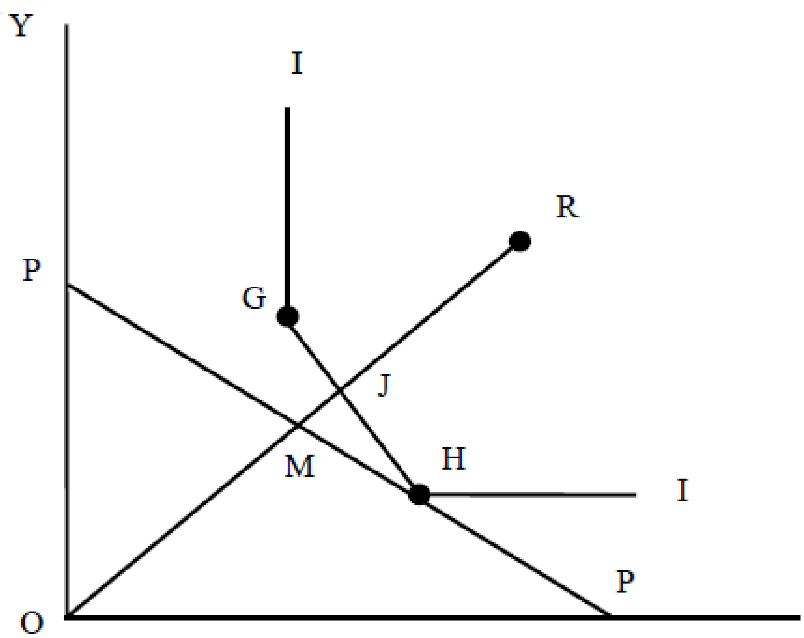
- Second, network models are based on an engineering approach. Instead of using economic or econometric/programming techniques, the analyst specifies the input and output factors as should be appropriate. Network models develop the optimal network on the basis of an engineering cost function, that is, they replicate consider the different variables and decision variables relevant to the network planning and replicate the process of constructing and operating the network.

39. Methods in this group involve different levels of established efficiency. Top-down network model involves economic-mathematical adjustments for efficiency. Bottom-up network models employ engineering and economic developments, and has two basic start approaches – scorched earth approach or scorched nodes approach.
40. Advantages of bottom-up network models include - modelling costs that an efficient entrant would face; flexibility since model-tool is designed as ready to change assumptions; transparency – in bottom-up models vast majority much of the information used is publicly available. Drawbacks of bottom-up network models include – risk of “too much” optimization or costs’ omitting; modeling of operating expenditure is usually based on simple margins instead of real-world costs; in some specific / limited cases data needed for the model might not exist; the regulatory process of modelling might take lengthy period and appear being relatively expensive one.
41. Advantages of top-down network models include – model incorporates actual costs instead of “theoretical” costs; can be used for testing purposes for bottom-up model; faster to develop and less costly to implement, however, only in those cases when accounting information (regulatory accounting, financial accounting) well matches the data required by the network model. Drawback of top-down network modelling include – since the model incorporates actual costs of an entity, so it does some inefficiencies either; less transparency – modelled entities might require certain extent of confidentiality over information regarded as commercially sensitive to the entity in questions either to third parties; prone to dispute the cost allocation rules; data might not exist in required form.
42. In practice, while developing network models as efficiency standard, regulators tend to use reconciled or hybrid models, which incorporate both approaches.
43. **<u>Choice of methodology</u>** will depend on:

- availability of data; in theory, if there is not enough data for individual entities, and only industry aggregate data is at hand, it is recommended to use PIN methods such as Tornqvist or Fisher indexes; econometric approaches are not recommended. When consistent physical input and output data is available, DEA or SFA are the choice, bearing in mind, that these two do not capture the effects of allocative efficiency changes;
- likely importance of data noise; while SFA attempts to account for noise, while DEA assumes it does not exist. So, when data is not of high quality, DEA is the choice to avoid. While using COLS, expert knowledge to adjust the intercept is used, and there is a space for some degree of target lobbying;
- intended use of the results; PIN analysis is to be used for industry-wide efficiency factor; if the goal is to set entity-specific factor, then DEA or SFA is used. One factor here comes of special importance – if an entity has plans of large capital investment over the regulatory period, the productivity growth is easier to achieve for this entity, than for an entity that has less planned investment. Application of many methods to cross-check as possible enables to minimize the possible impact of method selection on the results.

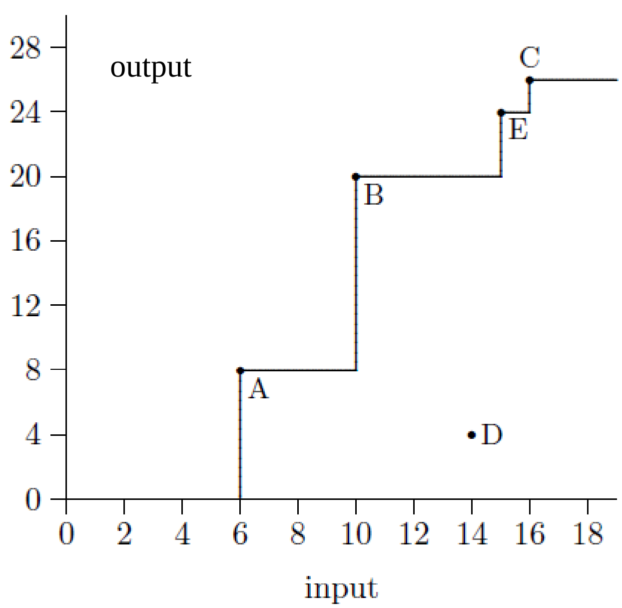
Annex 1.

Figure A-1. Calculating efficiency in DEA model



Technical efficiency measures the ability of an entity to minimize inputs to produce a given level of outputs, and here for entity R it is calculated as OJ/OR. Allocative efficiency reflects the ability of the entity to optimize the use of inputs given the price of the inputs, and here for the entity r it is calculated as OM/OJ. The overall efficiency of entity R is measured from OM/OR.

Figure A-2. Calculating efficiency in FDH model



A-3. Efficiency determination under OLS and COLS models

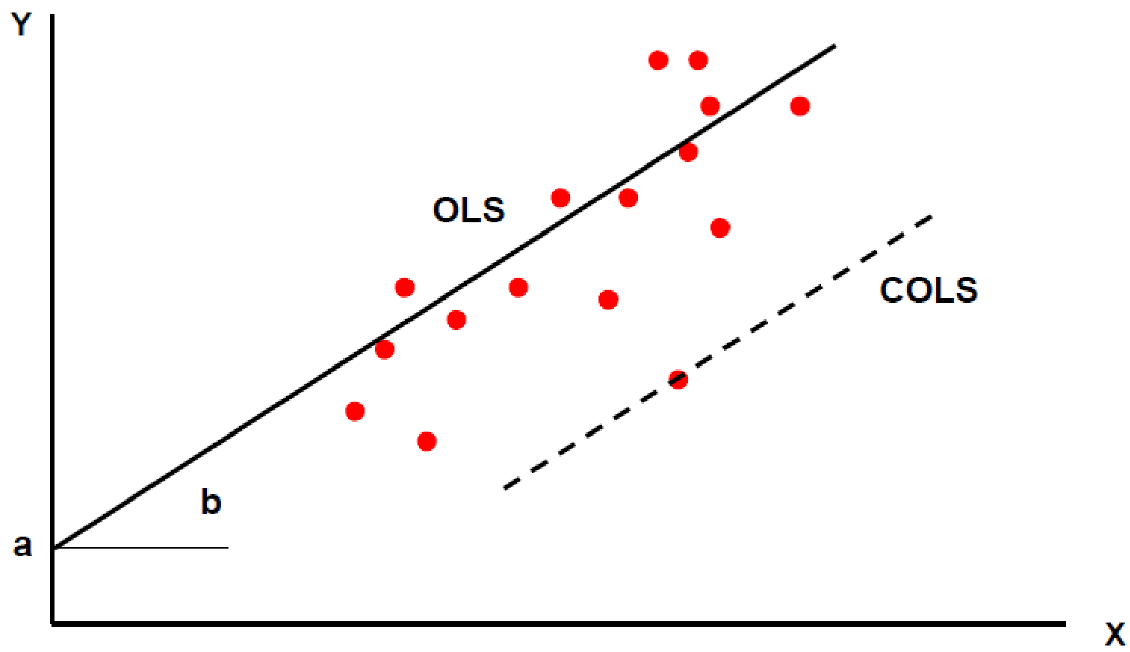


Figure A-4. Calculating efficiency in SFA model