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Efficiency Measurement and Regulation in U.S. Telecommunications: a Robustness Analysis*

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Abstract

The paper investigates the robustness of different efficiency measures that can support the implementation of diverse forms of incentive regulation in the context of U.S. telecommunications. Comparisons, in terms of an output orientation, are considered for efficiency scores obtained from Data Envelopment Analysis (DEA), distance function (with corrected ordinary least squares and a random effects model) and distance function embedded in a stochastic frontier framework (with time invariant, time varying efficiencies or with inefficiency effects). Similarly to the previous empirical literature, one finds, in most cases, only a moderate consistency across the different approaches. In fact, the different spectrum of techniques imposed varied degrees of structure in the error term and indicated non-negligible discrepancies across the different measurement approaches in terms of the ranking structure, degree of persistence and best and worst practices patterns.

Key-words: efficiency measurement, yardstick regulation

JEL classification: D29, L59, L96

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Introduction

The relevance of asymmetric information in regulated settings is by now largely recognized [see Laffont and Tirole (1993) for a comprehensive overview of the theoretical literature]. Yardstick regulatory schemes have been suggested as a possible relevant mechanism for partially mitigating the aforementioned asymmetries. Assuming that comparable and spatially separated utilities prevail, those approaches could, even if not directly implemented, provide useful guidance for designing incentive regulation schemes and setting the productivity offset. The relevance of different efficiency measurement techniques for devising benchmarking schemes was highlighted, for example, by Granderson and Linvil (1999) for natural gas transmission in the U.S. and by Tupper and Resende (2004) in the context of water and sewerage services in Brazil.

An essential step towards the implementation of any yardstick scheme pertains the adequate measurement of efficiency. In the context of telecommunications different contributions emerged in terms of non-parametric frontiers as exemplified by Majumdar (1995, 1997), Resende (2000), Uri (2001), Façanha and Resende (2000) and Resende and Façanha (2005) and distance functions as given by Uri (2002, 2003). An important focus of some of the previous studies referred to the efficiency and service-quality features of different regulatory regimes.

It is important, however, to further investigate the robustness of the efficiency scores under different approaches. With that respect, the literature is yet limited, and it is worth mentioning the works by Bauer et al (1998), Coelli and Perelman (1999) and Berg and Lin (2006) as respectively applied to financial institutions, railways and water utilities. The evidence indicates some robustness for a subset of techniques. In the present paper, one intends to undertake a broader spectrum of efficiency measurement techniques in the context of U.S. telecommunications. For that purpose, models with an increasing complexity in terms of the specification of the stochastic component are compared. Specifically, Data Envelopment Analysis-DEA nonparametric efficiency frontiers, traditional distance function and yet variants of models with distance functions embedded within a stochastic frontier framework.

The paper is organized as follows. The second section summarizes the conceptual aspects related to efficiency measurement in the context of the selected approaches. The third section discusses the data construction procedures and presents and compares the results accruing from the different approaches. The fourth section brings some final comments and suggestions for future research.

2. Efficiency Measurement: Some Conceptual Aspects

2.1-Introduction

A central feature of the telecommunications sector pertains its multi-output feature. Therefore, it is important to consider technology descriptions and measurement methods that properly deal with that aspect but are yet flexible in terms of data requirement. In fact, the most traditional cost function estimation or even stochastic cost frontiers require input prices data. In the context of U.S. telecommunications, one can highlight the applications considered by Shin and Ying (1992), Ying and Shin (1993) and Resende (1999) that considered flexible Translog cost function estimation with similar data construction procedures. It is possible, however, to ponder that deflating and user cost procedures make input prices construction difficult and potentially subject to criticisms [see e.g. by Gasmi et al. (2002)]. In this sense, from a practical perspective, it is relevant to consider multi-output approaches that require only quantity data but not necessarily in terms on nonparametric procedures.

The robustness exercise carried out in the present paper follows that route by considering the unifying notion of distance function. The concept outlined by Shephard (1970) is overviewed in Kumbhakar and Lovell-KL (2003). A distance function completely describes the technology and can be defined in terms of radial contraction or expansion movements depending on whether one focuses on input conservation or output expansion.

A basic working definition relates to the notion of output set considered in a setting with K inputs and M outputs and describes the set of output vectors that are feasible for each input vector x $\in R_{+}^{K}$, more precisely:

$$P(x) = \{y \in R_{+}^{M} : x \ can \ produce \ y\} \qquad (1)$$

The output distance function provides the minimum amount by which an output can be deflated and still remain feasible with a given input vector. In other words, one is considering feasible radial output expansion movements. Specifically:

$$D_O(x,y) = \min\{\theta : (y/\theta \in P(x)\} \qquad (2)$$

The properties of the output distance function follow from the properties of the output set and amongst those it is worth mentioning that D_{OI}(y,x) is non-decreasing, convex in y a homogeneous of degree 1 in output [see KL for details]. In particular, the last property implies that $D_O(x,\omega y) = \omega D_O(x,y)$ for any ω > 0 and in empirical practice will be contemplated upon output normalizations.[1] Next, different approaches based on that concept are briefly outlined.

2,2- Nonparametric approximation of the distance function

An influential and by now largely established approach is provided by Data Envelopment Analysis-DEA. This mathematical programming approach is extremely flexible and has given rise to a broad range of applications in different contexts. [see Cooper et al (2000) for an overview]. Unlike traditional econometric approaches that highlight average behaviours, that technique focuses on local comparisons to generate relative efficiency scores. A traditional formulation under variable returns to scale was advanced by Banker, Charnes and Cooper (1984)-BCC. Under an output orientation, one can conceive a situation where the aim is to maximize the ratio of a virtual

[1] Alternatively, input distance functions would emphasize input conservation. The two orientations are only necessarily equivalent under constant returns to scale. In the present paper I consider the output orientation throughout the comparison exercises across different techniques as the emphasis will be in the degree of structure conferred to the error term. In any case, it is often common that the orientation does not give rise to important differences in terms of the efficiency scores as for example is often the case in applications of Data Envelopment Analysis [see e.g. Berg and Lim (2006)].

output (composed as a weighted average of outputs) relative to a virtual input (composed as a weighted average of inputs) subject to non-negativity constraints on weights, a restriction imposing an upper bound for the efficiency scores and yet a convexity restriction given the variable returns to scale assumption. In the output oriented BCC model an equivalent linear programming program is solved for each for each decision making unit (DMU) (j=1,...,J) and here specified for the i-th unit. as follows:. The solution will enable to generate relative efficiency scores:

$$\max_{\phi_i, \lambda_i, s_i^-, s_i^+} \quad T_i = \phi_j + \varepsilon \sum_{k=1}^{K} s_{ik}^- + \varepsilon \sum_{m=1}^{M} s_{rk}^+ \qquad (3)$$

Subject to:

$$\sum_{j=1}^{J} \lambda_{ji} x_{kj} + s_{ki}^- = x_{ki} \qquad k = 1,\dots,K \qquad (4)$$

$$\sum_{j=1}^{J} \lambda_{ji} \; y_{mj} - s_{mi}^+ = \phi_i y_{mi} \qquad m = 1,\dots,M \qquad (5)$$

$$\sum_{j=1}^{J} \lambda_{ji} = 1 \qquad (6)$$

$$\lambda_{ji} \geq 0 \qquad (7)$$

$$s_{ki}^- \geq 0 \qquad (8)$$

$$s_{mi}^+ \geq 0 \qquad (9)$$

Where ε denotes a non-Archimedian quantity ($0 < \varepsilon < 1/N$ for any positive integer N) and s_{mi}^+ and s_{ki}^- indicate slacks. A DMU i is considered to be efficient if $\phi_i = 1$ and zero slacks prevail. In the application, given the panel data structure of the data. It is considered a window analysis procedure where each DMU is compared with the other DMUs and with itself in different periods. The largest possible window with 13 periods is considered.

2.3- <u>Parametric approximation of the distance function</u>

2.3.1- <u>Traditional econometric estimation</u>

Despite the flexibility of the notion of distance function, empirical applications, as previously mentioned, have been scarce. A first step refers to a flexible parameterization where the Translog function can play a relevant role. The steps for the empirical implementation are detailed, for example, in Lovell et al (1994) and Coelli and Perelman (2000). Under the referred parameterization one has:

$$TL \equiv \ln D_{Oi} = \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mi} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn} \ln y_{mi} \ln y_{ni} + \sum_{k=1}^{K} \beta_k \ln x_{ki}$$
$$+ \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{ki} \ln x_{li} + \sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{km} \ln x_{ki} \ln y_{mi} \qquad (10)$$

The homogeneity of degree 1 in outputs can be expressed in terms of the following conditions:

$$\sum_{m=1}^{M} \alpha_m = 1; \qquad \sum_{n=1}^{M} \alpha_{mn} = 0 \quad m = 1,2,..,M; \qquad \sum_{m=1}^{M} \delta_{km} = 0 \quad k = 1,2,..,K \qquad (11)$$

The symmetry conditions, on the other hand, require:

$$\alpha_{mn} = \alpha_{nm} \quad m,n = 1,2,..,M \qquad \beta_{kl} = \beta_{lk} \quad k,l = 1,2,...,K \qquad (12)$$

One is seeking a context where $-\infty <$ $D_{Oi} < 1$ where $D_{Oi} = 1$ indicates a point in the efficiency frontier. .The homogeneity condition, as implied by section 2.1, can be easily imposed by normalizing expression (10) by an arbitrary output (say y_{Mi}). Thus proceeding, one readily obtains:

$$-\ln(y_{Mi}) = TL(.) - \ln(D_{Oi}) \qquad i = 1,2,...,N \qquad (13)$$

The key step in the empirical implementation is to reinterpret the –ln(D_{Oi}) as an usual error term for econometric estimation. Assuming a simple bilateral structure for the error term, one can make use of a corrected ordinary least squares (COLS) procedure to obtain positive efficiency scores. Specifically, one considers in the case of the output orientation, exp((maximum negative residual)-(residual)) In other words, one adjusts the residuals in the opposite direction of a shift in the intercept so as to obtain meaningful positive efficiency scores. The OLS procedure, of course, imposes a strong stochastic assumption. A more flexible possibility for the estimation of distance functions, but usually ignored, would be to consider an analogous residual correction but with a random effects panel data model. In that case, a sub-component of the error term would be firm-specific and the resulting estimates would be more likely to capture unobserved heterogeneities. The two procedures in the empirical application will be denoted respectively by DF-OLS and DF-RE.

2.3.2- Distance function embedded in a stochastic frontier analysis framework

A usual criticism to non-parametric efficiency measurement approaches like DEA refers to its nearly deterministic character. In fact, discrepancies across different f units are solely attributed to inefficiencies. SFA, on the other hand, considers a composed error terms that separates efficiency and statistical noise but at the price of specific functional forms assumptions.[2] Nesting flexible multi-output distance function approaches within a SFA framework is

[2] When one considers robustness checks across different SFA approacjes, usually a reasonable consistency emerges [see e.g. Ahmad and Bravo-Ureta (1996)].

relatively uncommon and an exception is provided by Morrison Paul et al (2000). Standard procedures for SFA estimation readily follow when one considers a distance function approach except for a change in the sign of the error terms. In fact, in the efficiency frontier ln (D_{Oi}) = 0 imply that the composed error term will be reversed as (u_i-v_i) where the sub-components respectively stand for the statistical noise and technical efficiency. In order to conform with the standard SFA framework, one can change the sign of the dependent variable in standard software implementation and take care with the reversed interpretation of the coefficients.[3]

Among the large literature on SFA methods for panel data , it is worth emphasizing two works. Battese and Coelli (1992) considered a model with time-varying efficiency such that:

$$u_{it} = \eta_{it} u_i = \{\exp[-\eta(t-T)]\} u_i \qquad i = 1,..., N \qquad (15)$$

In this model U_{it} decreases, remains constant or increases with time if $\eta > 0$, $\eta = 0$ or $\eta < 0$ respectively. In the application, it always be considered the simplified setup of the normal/truncated-normal model where v_{it} and u_{it} are respectively assumed to be independent and identically distributed as N(0, ϖ_V^2) and N*(μ, σ_u^2), where former stands for a non-negative truncated normal distribution; Moreover, one assumes independence between those error sub-components We will consider in the application a model with time-varying efficiency (DF-SF-TN2) and the special case where $\eta = 0$ and the efficiency scores only display cross-sectional variation (DF-SF-TN1).

[3] Morrison Paul et al (2000) provides an application along those lines.

Finally, it is important to highlight a class of models with inefficiency effects as advanced by Battese and Coelli (1995). In this model, one incorporates the possibility that the mean of the efficiency error sub-component can be explained by other variables. More precisely, $\mu_{it} = z_{it}\delta$, where z_{it} denotes a (1 x r) vector of explanatory variables whereas δ indicates the associated (r x 1) vector of unknown parameters. This model will be referred as DF-SF-TN3.

3. Empirical Analysis

3.1-Data construction

The main data source of the present is the *Statistics of Communication Common Carriers* made available by the Federal Communications Commission. Given consolidations and some omissions, special care was taken to construct a balanced consistent panel of firms. The final sample comprises 30 local telephone companies (LECs) over the 1988-2000 period. The list of LECs in the sample is presented in appendix 1.

In order to explore the flexibility of the distance function approach, physical measures for inputs and outputs were considered whenever it was possible. The following inputs and outputs were considered:

Inputs

. EMP: total number of employees;

..COS: total number of central office switches;

. CAB: total miles of cable;

. MAT: quantity of materials approximated by (Operating Expenses- Labor Expenses-Depreciation Expenses) deflated by the general implicit price deflator for telecommunications (1996=100) obtained from the U.S. Bureau of Economic Analysis;

Outputs

. LOC: number of minutes-local calls;

. TOLL: number of minutes-toll calls ;

. ACC: number of minutes-access

Moreover. it is worth mentioning that ACC was used as the normalizing output to impose the homogeneity restriction and that in the model with inefficiency effect (DF-SF-TN3), a time trend was considered as the only explanatory factor affecting the mean of the (efficiency) error sub-component.

3.2- Comparing efficiency assessments: conceptual aspects

Even though efficiency measurement constitute an important element towards efficiency-based regulation, one encounters yet relatively few robustness exercises. In that sense, it is worth mentioning the evidence obtained from some selected studies for utilities. Coelli and Perelman (1999) considered European railways and undertook a comparative assessment of efficiency measures obtained from DEA, parametric linear programming (PLP) and distance function with COLS, under both input and output orientation. The evidence indicates strong correlation patterns across different techniques, especially in what concerns PLP and COLS. Berg and Lim (2006) considered the Peruvian water sector and compared the efficiency scores obtained from DEA (under different specifications) and an input distance function nested within a stochastic frontier framework-DF-SFA. In their case, the major focus of comparison related to an actual yardstick scheme implemented in that country (the SUNASS evaluation). In general terms, it is detected a moderate consistency in terms of rank correlations between DEA and the DF-SFA scores. Moreover, as is often the case, there is a high coherency between the DEA scores obtained from different orientations. The work by Bauer et al (1998) considered financial and undertook a comparative assessment of efficiency measurement with DEA, SFA, thick frontier approach (TFA) and distribution-free approach (DFA) and is particularly worth mentioning for suggesting guidelines for comparing the results from different measurement techniques. Before proceeding with the consistency analysis of the paper, let’s briefly consider some features of the efficiency scores presented in tables A1 through A6 in the appendix. In contrast with previous comparative exercises, one assesses the robustness of different approaches taking as reference the unifying notion of a distance function for comparing DEA, DF-OLS, DF-RE, DF-SF-TN1, DF-SF-TN2 and DF-SF-TN3. As mentioned before, the models vary in complexity by either specifying no structure for the stochastic term, specifying a bilateral error or yet a composed error structure. The former case occurs with the nesting of a distance function within a SFA framework that can incorporate or not time-varying efficiencies and inefficiency effects. The possible combinations are numerous and the six models exhibit important discrepancies and patterns in a first inspection of the tables A1 through A6 displayed in appendix 2, most notably:[4]

i) The evolution of efficiency is not always monotonic and erratic trajectories occasionally prevail with abrupt reversals as for example in the case of DF-OLS;

ii) Substantial underperformance arises in the case of the SFA methodologies

iii) Model explicitly allowing for time-varying efficiencies like DF-SF-TN2 indicate negligible changes in efficiency.

Some relevant consistency criteria would be as follows;

a) <u>Comparisons of efficiency distributions with each other</u>

The authors compared descriptive statistics in general for the different efficiency scores and paid particular attention to the temporal evolution of the average efficiency under the different approaches. As expected, one detected great discrepancies across the absolute values of those average scores. In fact, one should remember in particular that DEA scores are obtained from local efficiency comparisons whereas econometric-based models always impose some kind of average behavior. A more fruitful approach would be the focus on co-movements rather than the absolute values of the scores. In that sense, a multivariate analysis of the stacked efficiency scores vectors can be

[4] Since the focus of the paper is on the consistency of the efficiency scores associated with different approaches, the intermediate estimation results will not be presented for conciseness. The results , that indicated a good fit, can be provided upon request. The empirical results ere obtained with the softwares DEA-Solver Professional (DEA), Eviews 5.1 (DF-OLS and DF-RE) and Frontier 4.1 by Tim Coelli (DF-SF-TN1. DF-SF-TN2 and DF-SF-TN3)

useful. In order to detect the presence of common dimensions among the different measures of efficiency, the multivariate statistical technique of principal components analysis-PCA can be appropriate. The technique considers linear combinations of the p original variables X_j's (j = 1,…, p) with generic expression for the i-th principal component given (with a slight abuse of notation) by:

$$Z = a_{i1}X_1 + ... + a_{ip}X_p$$

The coefficients of the linear combination are established such that the first principal component captures the most expressive part of data variation. The following principal components capture a decreasing portion of the data variation. The principal components are pairwise orthogonal in the sense that different principal components capture independent dimensions of the data. [5] A common criterion for assessing the contribution of the different principal components relates to the magnitude of the eigenvalues of the correlation matrix of the original data[6] and one would retain those that exceed 1 or yet seek a cumulative variance of more than some specified value (typically 75%) The evidence accruing from the PCA is summarized in tables 1 and 2, and indicates that under both criteria one should retain only the first 2 principal components and therefore it is possible to detect important common dimensions and co-movements across the efficiency scores obtained from the alternative techniques. Moreover, the positive coefficients of the components matrix with respect to the first component reflects a general efficiency

[5] For a useful introduction to multivariate statistical methods see Manly (1994).
[6] In that case the variances of the principal components would add up to p.

component whereas one observes negative coefficients of the second component with respect to DF-RE, DF-SF-TN1and DF-SF-TN2. Even though, the results are not clear cut they might indicate that the allowance for persistence in the error term differentiate some efficiency measures beyond the capacity of capturing a common overall efficiency.

INSERT TABLES 1 AND 2 AROUND HERE

b) Rank order correlation of the efficiency distributions

The consideration of yardstick schemes poses an important role to the order structure of efficiency scores. In fact, one should seek a reasonable coherency in terms of rank correlations between different measures. Otherwise, specific measures must be carefully chosen with some a priori justification. The evidence is presented in table 3 below.

INSERT TABLE 3 AROUND HERE

In general only moderate coherency arises between the different measures though some relatively high correlations are present between some distance function approaches (direct econometric estimation and some versions embedded with SFA). The observed magnitudes are not strikingly contrasting with previous evidence obtained by Bauer et al (1998) and Berg and Lim (2006) in different sectors and in part with different measurement approaches.

The results therefore suggests that there are important differences in the order structure across distinct efficiency measures.

c)<u>Identification of Best-Practice and Worst-Practice Firms</u>

Even though the coherence in terms of rank correlations might be limited in occasions one might be interested in inspecting more closely the tails of distributions of efficiency scores. Indeed, from a benchmarking perspective, a good capacity of identifying best-practice and worst-practice units could still be useful. The related evidence is presented in table 4.

INSERT TABLE 4 AROUND HERE

The evidence indicates the proportion of matching between pairs of techniques for the top 20% and lower 20% utilities. The matching coherency is only moderate and with similar magnitudes as those obtained by Bauer at al (1998) in a different context. Moreover, one does not notice any particularly asymmetric ability on detecting best or worst practices.

d)<u>Stability of Measured Efficiency over Time</u>

From a regulatory perspective, one should seek efficiency patterns that display some relative stability or consider some average behavior within some carefully chosen time window. Next, table 5 indicates the persistence of efficiency by considering the average correlations for different time intervals. The evidence is not always clear cut as in some cases a substantial proportion of non-significant correlations arise. The trivial case of the DF-SF-TN1 model is not reported as it imposes time-invariant efficiencies. For the other approaches one detects a substantial degree of persistence with very slow decay as the time distance increases with the exception of DF-OLS that initially displays moderate values for the correlations that rapidly decline afterwards. the movements just described were predominantly monotonic. In summary, persistence appears to be an important feature and might be potentially interested in adopting techniques that explicitly account for that stylized fact.

INSERT TABLE 5 AROUND HERE

4. Final Comments

The paper aimed at investigating the robustness of different efficiency measurement approaches in the context of the U.S. telecommunications as potentially supportive to incentive regulatory practices. The paper adopted the unifying concept of a distance function to characterize a multi-output technology in a flexible manner. Similarly to the previous empirical literature, one finds, in most cases, only a moderate consistency across the different approaches. In fact, the different spectrum of techniques imposed varied degrees of structure in the error term and indicated non-negligible discrepancies across the different measurement approaches in terms of the ranking structure, degree of persistence and best and worst practices patterns.

Even though, the stochastic frontier literature provides a more precise modeling of the error sub-components in terms of statistical noise and efficiency it possesses shortcomings related with the specific functional form assumptions. Moreover, a reliable estimation require relatively large panel data sets that would extrapolate a typical regulatory period of 4-5 years, whereas a long panel only would be meaningful in the case of less dynamic industries. This last aspect underscores the fact that yardstick schemes are more feasible in sectors with a simple technology like the water industry for example. In fact, rapid technical changes observed in the telecommunications industry make the utilization of long panels questionable. [7]

The aforementioned caveats indicate a possible useful role for non-parametric efficiency measurement methods like DEA that displayed some consistency with the more general specification of the SFA approach with inefficiency effects (in this paper DF-SF-HN3**)**; The flexibility of non-parametric approaches can be relevant in regulatory settings, but in that case a careful stochastic treatment by means of bootstrap re-sampling methods can be valuable [see e.g. Simar (1992)].

[7] More recently, the growing adoption of voice over IP procedures is an example of an important structural change that is difficult to control for in efficiency measurement exercises.

References

Ahmad, M., Bravo-Ureta, B.E. (1996), Technical efficiency measures for dairy farms using panel data: a comparison of alternative model specifications, *Journal of Productivity Analysis*, 7, 399-415

Banker, R.D., Charnes, A., Cooper, W.W. (1984), Some models for estimating technical and scale inefficiencies in data envelopment analysis, *Management Science*, 30, 1078-1092

Bauer, B.W., Berger, A.N., Ferrier, G.D., Humphrey, D.B. (1998), Consistency conditions for regulatory analysis of financial institutions: a comparison of frontier efficiency methods, *Journal of Economics and Business*, 50, 85-114

Berg, S., Lin, C. (2006), Consistency in performance rankings: the Peru water sector, University of Florida, mimeo

Coelli, T., Perelman, S. (1999), A comparison of parametric and non-parametric distance functions: with application to European railways, *European Journal of Operational Research*, 117, 326-339

Coelli, T., Perelman, S. (2000), Technical efficiency of European railways. A distance function approach, *Applied Economics*, 32, 1967-1976

Cooper, W.W., Seford, L.M., Tone, K. (2000), *Data Envelopment Analysis*, Boston: Kluwer Academic Publishers

Façanha, L.O., Resende, M. (2004), Price cap regulation, incentives and quality: the case of Brazilian telecommunications, *International Journal of Production Economics*, 92, 133-144

Gasmi, F., Kennet, D.M., Laffont, J.J., Sharkey, W.W. (2002), *Cost Proxy Models and Telecommunication Policy*, Cambridge-MA: MIT Press

Granderson, G., Linvill, C. (1999), Parametric and nonparametric approaches to benchmarking the regulated firm, *Journal of Productivity Analysis*, 12, 211-231

Kumbhakar, S.C., Lovell, C.A.K. (2003), *Stochastic Frontier Analysis*, Cambridge: Cambridge University Press

Laffont, J.J., Tirole, J. (1993), *A Theory of Incentives in Procurement and Regulation*, Cambridge-MA: MIT Press

Lovell, C.A.K., Richardson, S., Travers, P., Wood, L. (1994), Resources and functionings: a new view of inequality in Australia, In W. Eichhorn (ed.), *Models and Measurement of Welfare and Inequality*, Berlin: Springer-Verlag, 787-807

Majumdar, S. (1995), X-efficiency in emerging competitive markets. The case of U.S. telecommunications, *Journal of Economic Behavior and Organization*, 26, 129-144

Majumdar, S. (1997), Incentive regulation and productive efficiency in the U.S. telecommunications industry, *Journal of Business*, 70, 547-576

Manly, B.F. (1994), *Multivariate Statistical Methods*, London: Chapman & Hall

Morrison Paul, C.J., Johnston, W.E, Frengley, G.A.G. (2000), Efficiency in New Zealand Sheep and Beef Farming: the Impacts of Regulatory Reform, *Review of Economics and Statistics*, 82, 325-337

Resende, M. (1999), Productivity Growth and Regulation in U.S. Local Telephony, *Information Economics and Policy*, 11, 23-44

Resende, M. (2000), Regulatory regimes and efficiency in U.S. local telephony, *Oxford Economic Papers*, 52, 447-70

Resende, M., Façanha, L.O. (2005), Price cap regulation and service-quality in telecommunications: an empirical study, *Information Economics and Policy*, 17, 1-12

Shin, R.T., Ying, J.S. (1992), Unnatural monopolies in local telephone, *RAND Journal of Economics*, 23, 171-183

Simar, :L. (1992), Estimating Efficiencies from Frontier Models with Panel Data: A Comparison of Parametric,Frontier, Non-parametric and Semi-parametricMethods with Bootstrapping, *Journal of Productivity Analysis*, 2. 167-203

Tupper, H.C., Resende, M. (2004), Efficiency and Regulatory Issues in the Brazilian Water and Sewage Sector: an Empirical Study, *Utilities Policy*, 12, 29-40

Uri, N. (2001), The effect of incentive regulation on productive efficiency in telecommunications, *Journal of Policy Modeling*, 23, 825-846

Uri, N. (2002), Measuring the change in productive efficiency in telecommunications in the USA, *Journal of Economic Studies*, 29, 150-167

Uri, N. (2003), The adoption of incentive regulation and Its effects on technical efficiency in telecommunications in the United States, *International Journal of Production Economics*, 86, 21-34

Ying, J.S., Shin, R.T. (1993), Costly gains in breaking up: LECS and the baby Bells, *Review of Economics and Statistics*, 76, 357-361

Table 1

Principal Components for Efficiency Scores across Different Techniques-
Explained Variance

Principal components	variance	proportion of total variance (%)	cumulative proportion of total variance (%)
1	3.624	60.408	60.408
2	1.328	22.141	82.549
3	0.520	8.671	91.220
4	0.336	5.594	96.814
5	0.125	2.090	98.904
6	6.578E-02	1.096	100.00

Table 2

Principal Components for Efficiency Scores across Different Techniques-Components Matrix

Technique	**Component 1**	**Component 2**
DEA	0.797	0.258
DF-OLS	0.657	0.583
DF-RE	0.912	-0.208
DF-SF-TN1	0.789	-0.563
DF-SF-TN2	0.842	-0.415
DF-SF-TN3	0.629	0.625

Table 3
Spearman Rank-Order Correlations Among the Efficiency Scores Created by Different Approaches

	DEA	DF-OLS	DF-RE	DF-SF-TN1	DF-SF-TN2	DF-SF-TN3
DEA	1.000	0.580 (0.000)	0.540 (0.000)	0.443 (0.000)	0.597 (0.000)	0.649 (0.000)
DF-OLS		1.000	0.585 (0.000)	0.278 (0.000)	0.372 (0.000)	0.767 (0.000)
DF-RE			1.000	0.849 (0.000)	0.826 (0.000)	0.440 (0.000)
DF-SF-TN1				1.000	0.852 (0.000)	0.177 (0.000)
DF-SF-TN2					1.000	0.517 (0.000)
DF-SF-TN3						1.000

Note: the p-values are reported in parentheses for the non-trivial correlations

Table 4

Correspondence of Best Practice and Worst Practice LECs across Techniques (Upper triangle shows best practice , and lower triangle shows worst practice)

	DEA	**DF-OLS**	**DF-RE**	**DF-SF-TN1**	**DF-SF-TN2**	**DF-SF-TN3**
DEA		0.423	0.474	0.487	0.513	0.385
DF-OLS	0.500		0.551	0.372	0.359	0.770
DF-RE	0.410	0.474		0.756	0.718	0.423
DF-SF-TN1	0.500	0.333	0.718		0.692	0.244
DF-SF-TN2	0.551	0.320	0.667	0.744		0.462
DF-SF-TN3	0.551	0.513	0.308	0.333	0.372	

Note: one considered the upper and lower 20% of the distribution

Table 5

Persistence of Efficiency-Correlations of n Years Apart Efficiencies

Technique	1 year apart	2 years apart	3 years apart	4 years apart	5 years apart	6 years apart	7 years apart	8 years apart	9 years apart	10 years apart	11 years apart	12 years apart
DEA	0.857 (1.000)	0.762 (1.000)	0.726 (1.000)	0.704 (1.000)	0.707 (1.000)	0.693 (1.000)	0.636 (1.000)	0.568 (1.000)	0.596 (0.750) (0.514)	0.639 (0.667) (0.494)	0.564 (1.000)	0.564 (1.000)
DF-OLS	0.582 (0.833) (0.526)	0.549 (0.364) (0.357)	0.526 (0.300) (0.249)	0.409 (0.333) (0.274)	0.269 (0.375) (0.291)	0.432 (0.286) (0.227)	0.422 (0.167) (0.209)	0.329 (0.200) (0.160)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
DF-RE	0.911	0.870	0.844	0.838	0.823	0.820	0.804	0.776	0.733	0.733	0.737	0.733
DF-SF-TN2	0.999	0.999	0.998	0.997	0.995	0.994	0.991	0.988	0.986	0.982	0.978	0.974
DF-SF-TN3	0.711 (0.750) (0.578)	0.542 (0.636) (0.388)	0.642 (0.200) ((0.280)	0.398 (0.556) (0.289)	0.429 (0.625) (0.299)	0.480 (0.714) (0.394)	0.485 (0.500) (0.400)	0.407 (0.600) (0.322)	0.508 (0.250) (0.198)	0.370 (0.333) (0.190)	0.000 (0.000)	0.000 (0.000)

Notes:
a) The first value in each cell of the table corresponds to the average of the correlations of the n-years-apart efficiencies. The averages are computed over the 13-n correlations in each case, considering the ones that were significant at the 10% level
b)The first term in parentheses represents the proportion of cases that were significant at the 10% level, whereas the second term in parentheses indicates the average of all correlations

Appendix 1

List of local exchange carriers-LECs

1) Bell-IL: Illinois Bell Telephone Company
2) Bell-IN: Indiana Bell Telephone Company
3)Bell-MI: Michigan Bell Telephone Company
4) Bell-OH: Ohio Bell Telephone Company
5)Bell-WI: Wisconsin Bell Inc.
6)Ver-DC: Verizon Washington D.C. Inc.
7)Ver-MD: Verzon Maryland
8) Ver-VA: Verzon Virginia
9) Ver-WV: Verzon West Virginia
10) Ver-DE: Verizon Delaware
11) Ver-PA: Verizon Pennsylvania
12) Ver-NJ: Verizon New Jersey
13) Ver-NE: Verizon New England
14) Ver-NY: Verizon New York
15) Nev. Bell: Nevada Bell
16) Pac. Bell. Pacific Bell
17) SW Bell. Southwestern Bell Telephone Company
18) Cinc. Bell: Cincinatti Bell Telephone Compoany
19) SNE: Southern New England Telephone Company
20) Centel-VA: Central Telephone Company of Virginia
21) Ver-CA: Verizon Califórnia Inc.
22) Ver-FL: Verizon Florida Inc.
23) Ver-HI: Verizon Hawaii Inc.
24) Ver-NO: Verizon North Inc.
25) Ver-NW: Verizon Northwest Inc.
26) Ver-SO: Verizon South Inc.
27) PR-Telco: Puerto Rico telephone Company
28) UT-IN: United Telephone Company of Indiana
29) UT-OH: United Telephone Company of Ohio
30) UT-PA:: United Telephone Company of Pennsylvania

APPENDIX 2

Table A1 - Efficiency Scores-Data Envelopment Analysis-BCC model-output orientation

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Bell-IL	0.817	0.882	0.953	0.885	0.901	0.943	0.978	0.987	1.000	0.991	1.000	1.000	0.961
Bell-IN	0.620	0.601	0.605	0.599	0.703	0.717	0.784	0.841	0.912	0.930	0.979	1.000	0.964
Bell-MI	0.692	0.708	0.751	0.726	0.699	0.672	0.760	0.759	0.834	0.778	0.797	0.884	0.863
Bell-OH	0.733	0.719	0.729	0.775	0.785	0.825	0.843	0.947	1.000	0.987	1.000	1.000	0.954
Bell-WI	0.564	0.542	0.516	0.545	0.552	0.607	0.658	0.710	0.777	0.793	0.911	0.957	1.000
Ver-DC	1.000	1.000	1.000	1.000	1.000	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ver-MD	0.726	0.754	0.736	0.731	0.773	0.779	0.835	0.982	1.000	0.990	0.982	0.997	0.904
Ver-VA	0.718	0.675	0.695	0.690	0.742	0.727	0.721	0.902	0.976	0.988	1.000	1.000	0.947
Ver-WV	0.413	0.416	0.436	0.449	0.484	0.468	0.539	0.730	0.762	0.760	0.805	0.805	0.852
Ver-DE	1.000	1.000	1.000	0.827	0.815	0.735	0.711	0.847	1.000	0.978	1.000	1.000	0.993
Ver-PA	0.732	0.727	0.752	0.746	0.755	0.740	0.771	0.887	0.946	0.936	0.970	1.000	0.961
Ver-NJ	0.800	0.766	0.810	0.785	0.750	0.758	0.774	0.850	0.932	1.000	0.981	1.000	1.000
Ver-NE	0.654	0.568	0.557	0.540	0.570	0.604	0.568	0.715	0.592	0.588	0.711	0.777	0.827
Ver-NY	0.639	0.578	0.617	0.603	0.632	0.646	0.684	0.715	0.742	0.752	0.761	1.000	0.981
Nev. Bell	1.000	1.000	1.000	0.854	0.830	0.933	1.000	1.000	1.000	0.955	1.000	1.000	0.767
Pac. Bell	0.777	0.776	0.795	1.000	0.901	0.921	0.922	0.936	1.000	1.000	1.000	1.000	1.000
SW Bell	0.855	0.927	0.935	0.966	0.952	0.932	0.970	0.999	1.000	0.983	1.000	1.000	1.000
Cinc. Bell	0.696	0.696	0.631	0.635	0.637	0.663	0.709	0.749	0.829	1.000	0.898	0.955	0.960
SNE	0.512	0.504	0.511	0.498	0.525	0.541	0.540	0.554	0.667	0.670	0.679	0.529	0.617
Centel-VA	1.000	0.721	0.727	0.807	0.691	0.680	0.628	0.756	0.980	1.000	1.000	1.000	1.000
Ver-CA	1.000	0.773	0.568	0.612	0.795	0.692	0.694	0.850	0.668	0.721	0.754	0.879	1.000
Ver-FL	0.522	0.404	0.471	0.506	0.599	0.586	0.504	0.801	0.694	0.795	0.736	0.822	0.697
Ver-HI	0.641	1.000	0.597	0.577	0.597	0.582	0.575	0.603	0.581	0.641	0.666	0.746	0.888
Ver-NO	0.499	0.466	0.475	0.501	0.569	0.570	0.579	0.636	0.617	0.682	0.650	0.879	1.000
Ver-NW	0.380	0.059	0.365	0.388	0.418	0.415	0.435	0.641	0.596	0.661	0.785	0.837	0.800
Ver-SO	0.299	0.251	0.330	0.347	0.408	0.445	0.465	0.605	0.603	0.635	0.671	0.745	1.000
PR Telco	0.438	0.594	0.534	0.605	0.643	0.535	0.504	0.453	0.622	0.659	0.722	0.720	0.780
UT-IN	1.000	0.851	0.679	1.000	0.692	0.507	0.614	0.673	1.000	1.000	1.000	0.876	1.000
UT-OH	0.298	0.280	0.427	0.512	0.496	0.444	0.461	0.469	0.691	0.669	0.716	0.583	0.635
UT-PA	0.467	0.345	1.000	1.000	0.458	0.368	0.415	0.407	0.775	0.732	0.605	0.570	0.646

Table A2 - Efficiency Scores-Input Distance Function-(corrected) ordinary least squares model

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Bell-IL	0.634	0.622	0.802	0.554	0.539	0.556	0.608	0.537	0.603	0.603	0.609	0.610	0.553
Bell-IN	0.498	0.458	0.450	0.419	0.472	0.512	0.527	0.519	0.640	0.612	0.602	0.599	0.548
Bell-MI	0.426	0.421	0.437	0.424	0.399	0.372	0.512	0.401	0.455	0.418	0.380	0.422	0.358
Bell-OH	0.531	0.505	0.504	0.520	0.492	0.504	0.550	0.507	0.592	0.561	0.542	0.567	0.479
Bell-WI	0.445	0.442	0.390	0.382	0.369	0.383	0.432	0.455	0.489	0.466	0.429	0.441	0.398
Ver-DC	0.514	0.449	0.649	0.582	0.598	0.571	0.593	0.457	0.421	0.451	0.465	0.418	0.418
Ver-MD	0.498	0.516	0.530	0.483	0.518	0.512	0.538	0.565	0.566	0.571	0.609	0.639	0.627
Ver-VA	0.480	0.460	0.497	0.451	0.486	0.457	0.444	0.463	0.473	0.484	0.491	0.512	0.500
Ver-WV	0.368	0.422	0.414	0.410	0.445	0.410	0.433	0.487	0.508	0.590	0.598	0.612	0.611
Ver-DE	0.391	0.370	0.478	0.472	0.470	0.460	0.477	0.508	0.581	0.666	0.731	0.693	0.598
Ver-PA	0.475	0.485	0.532	0.494	0.496	0.491	0.494	0.498	0.519	0.560	0.566	0.598	0.527
Ver-NJ	0.499	0.409	0.493	0.489	0.452	0.461	0.560	0.431	0.483	0.505	0.611	0.665	0.672
Ver-NE	0.443	0.400	0.397	0.366	0.396	0.421	0.328	0.382	0.293	0.288	0.361	0.417	0.398
Ver-NY	0.358	0.351	0.410	0.369	0.437	0.427	0.358	0.362	0.416	0.410	0.396	0.507	0.517
Nev. Bell	0.455	0.384	0.426	0.417	0.424	0.407	0.539	0.523	0.477	0.514	0.445	0.623	0.403
Pac. Bell	0.433	0.444	0.468	1.000	0.538	0.573	0.536	0.526	0.674	0.560	0.599	0.519	0.457
SW Bell	0.412	0.453	0.457	0.460	0.494	0.446	0.463	0.471	0.559	0.583	0.575	0.533	0.525
Cinc. Bell	0.422	0.423	0.376	0.405	0.423	0.458	0.502	0.392	0.580	0.745	0.543	0.591	0.596
SNE	0.363	0.362	0.368	0.339	0.437	0.444	0.407	0.378	0.520	0.460	0.411	0.294	0.258
Centel-VA	0.587	0.504	0.487	0.479	0.486	0.498	0.441	0.483	0.495	0.569	0.443	0.334	0.365
Ver-CA	0.732	0.542	0.450	0.489	0.608	0.546	0.503	0.509	0.517	0.520	0.543	0.668	0.894
Ver-FL	0.257	0.271	0.401	0.498	0.607	0.563	0.199	0.617	0.636	0.773	0.620	0.727	0.536
Ver-HI	0.399	0.726	0.455	0.461	0.475	0.440	0.378	0.360	0.399	0.481	0.448	0.592	0.703
Ver-NO	0.570	0.477	0.422	0.361	0.405	0.393	0.381	0.351	0.385	0.422	0.377	0.570	0.714
Ver-NW	0.422	0.295	0.421	0.525	0.427	0.389	0.404	0.360	0.476	0.538	0.526	0.783	0.633
Ver-SO	0.294	0.355	0.410	0.428	0.433	0.412	0.438	0.334	0.459	0.486	0.520	0.626	0.902
PR Telco	0.284	0.462	0.428	0.430	0.483	0.902	0.410	0.391	0.389	0.406	0.447	0.457	0.536
UT-IN	0.712	0.644	0.552	0.492	0.427	0.348	0.351	0.371	0.610	0.535	0.555	0.382	0.487
UT-OH	0.333	0.308	0.534	0.571	0.516	0.471	0.471	0.467	0.707	0.667	0.649	0.394	0.437
UT-PA	0.400	0.267	0.518	0.508	0.405	0.333	0.368	0.358	0.623	0.593	0.454	0.309	0.386

Table A3 – Efficiency Scores-Input Distance Function-(corrected) random effects model

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Bell-IL	0.713	0.714	0.848	0.663	0.643	0.660	0.664	0.633	0.676	0.671	0.662	0.648	0.612
Bell-IN	0.453	0.427	0.420	0.402	0.456	0.468	0.460	0.499	0.560	0.534	0.529	0.521	0.488
Bell-MI	0.386	0.382	0.405	0.393	0.374	0.350	0.424	0.363	0.378	0.356	0.328	0.337	0.301
Bell-OH	0.543	0.527	0.530	0.547	0.525	0.528	0.559	0.544	0.599	0.562	0.542	0.534	0.479
Bell-WI	0.447	0.450	0.414	0.411	0.400	0.417	0.441	0.453	0.470	0.441	0.417	0.431	0.399
Ver-DC	0.770	0.704	0.959	0.913	0.934	0.914	0.944	0.822	0.797	0.828	0.842	0.777	0.753
Ver-MD	0.524	0.579	0.579	0.530	0.547	0.553	0.580	0.613	0.611	0.592	0.612	0.639	0.633
Ver-VA	0.492	0.491	0.504	0.459	0.479	0.458	0.441	0.463	0.485	0.480	0.480	0.492	0.482
Ver-WV	0.304	0.366	0.343	0.349	0.373	0.348	0.358	0.408	0.417	0.448	0.453	0.448	0.443
Ver-DE	0.437	0.463	0.522	0.520	0.525	0.490	0.494	0.557	0.634	0.675	0.716	0.683	0.611
Ver-PA	0.442	0.530	0.562	0.518	0.518	0.510	0.502	0.510	0.521	0.540	0.544	0.567	0.505
Ver-NJ	0.653	0.567	0.678	0.651	0.582	0.590	0.652	0.544	0.595	0.631	0.711	0.765	0.775
Ver-NE	0.402	0.380	0.374	0.334	0.352	0.368	0.314	0.357	0.269	0.269	0.336	0.372	0.356
Ver-NY	0.461	0.476	0.565	0.503	0.562	0.552	0.486	0.485	0.557	0.559	0.541	0.694	0.703
Nev. Bell	0.437	0.395	0.414	0.407	0.412	0.402	0.499	0.497	0.478	0.489	0.512	0.634	0.438
Pac. Bell	0.559	0.563	0.586	1.000	0.644	0.675	0.634	0.620	0.723	0.674	0.704	0.652	0.602
SW Bell	0.332	0.366	0.376	0.358	0.365	0.365	0.370	0.374	0.453	0.482	0.480	0.468	0.456
Cinc. Bell	0.551	0.609	0.545	0.556	0.565	0.593	0.640	0.567	0.716	0.958	0.724	0.752	0.707
SNE	0.412	0.408	0.414	0.388	0.498	0.505	0.466	0.439	0.565	0.490	0.442	0.306	0.300
Centel-VA	0.333	0.302	0.289	0.283	0.298	0.304	0.277	0.296	0.321	0.349	0.281	0.256	0.263
Ver-CA	0.828	0.680	0.506	0.551	0.655	0.581	0.549	0.575	0.510	0.523	0.542	0.610	0.801
Ver-FL	0.333	0.310	0.410	0.488	0.562	0.537	0.279	0.571	0.589	0.705	0.633	0.700	0.564
Ver-HI	0.486	0.582	0.517	0.516	0.531	0.517	0.469	0.442	0.478	0.550	0.545	0.632	0.746
Ver-NO	0.229	0.200	0.195	0.168	0.178	0.173	0.168	0.151	0.165	0.173	0.167	0.217	0.289
Ver-NW	0.368	0.213	0.339	0.380	0.322	0.287	0.299	0.268	0.339	0.391	0.387	0.530	0.453
Ver-SO	0.159	0.225	0.258	0.260	0.255	0.303	0.210	0.185	0.243	0.261	0.284	0.329	0.484
PR Telco	0.321	0.413	0.387	0.380	0.427	0.677	0.367	0.349	0.363	0.382	0.402	0.438	0.473
UT-IN	0.411	0.379	0.299	0.269	0.252	0.223	0.228	0.242	0.360	0.326	0.321	0.254	0.300
UT-OH	0.200	0.189	0.315	0.336	0.318	0.298	0.299	0.299	0.416	0.395	0.391	0.277	0.296
UT-PA	0.247	0.181	0.310	0.303	0.254	0.223	0.242	0.241	0.370	0.350	0.288	0.223	0.256

Table A4 – Efficiency Scores-Output Distance Function-Normal/Half Normal model-Time Invariant Efficiencies

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Bell-IL	0.663	0.663	0.663	0.663	0.663	0.663	0.663	0.663	0.663	0.663	0.663	0.663	0.663
Bell-IN	0.497	0.497	0.497	0.497	0.497	0.497	0.497	0.497	0.497	0.497	0.497	0.497	0.497
Bell-MI	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402
Bell-OH	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580
Bell-WI	0.520	0.520	0.520	0.520	0.520	0.520	0.520	0.520	0.520	0.520	0.520	0.520	0.520
Ver-DC	0.937	0.937	0.937	0.937	0.937	0.937	0.937	0.937	0.937	0.937	0.937	0.937	0.937
Ver-MD	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608
Ver-VA	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.576
Ver-WV	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336
Ver-DE	0.584	0.584	0.584	0.584	0.584	0.584	0.584	0.584	0.584	0.584	0.584	0.584	0.584
Ver-PA	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540
Ver-NJ	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888	0.888
Ver-NE	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368
Ver-NY	0.548	0.548	0.548	0.548	0.548	0.548	0.548	0.548	0.548	0.548	0.548	0.548	0.548
Nev. Bell	0.390	0.390	0.390	0.390	0.390	0.390	0.390	0.390	0.390	0.390	0.390	0.390	0.390
Pac. Bell	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585
SW Bell	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335
Cinc. Bell	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630
SNE	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438	0.438
Centel-VA	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240	0.240
Ver-CA	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490	0.490
Ver-FL	0.436	0.436	0.436	0.436	0.436	0.436	0.436	0.436	0.436	0.436	0.436	0.436	0.436
Ver-HI	0.396	0.396	0.396	0.396	0.396	0.396	0.396	0.396	0.396	0.396	0.396	0.396	0.396
Ver-NO	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152
Ver-NW	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280
Ver-SO	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224	0.224
PR Telco	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222
UT-IN	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198
UT-OH	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206	0.206
UT-PA	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175

Table A5 – Efficiency Scores-Output Distance Function- Normal/Half Normal model-Time Varying Efficiencies

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Bell-IL	0.306	0.322	0.339	0.356	0.372	0.389	0.405	0.422	0.438	0.455	0.471	0.487	0.502
Bell-IN	0.181	0.195	0.210	0.225	0.240	0.256	0.272	0.288	0.304	0.321	0.337	0.354	0.370
Bell-MI	0.156	0.170	0.183	0.198	0.212	0.227	0.243	0.258	0.274	0.290	0.307	0.323	0.340
Bell-OH	0.234	0.249	0.265	0.281	0.297	0.314	0.330	0.347	0.363	0.380	0.397	0.413	0.430
Bell-WI	0.187	0.202	0.217	0.232	0.247	0.263	0.279	0.295	0.312	0.328	0.345	0.361	0.378
Ver-DC	0.937	0.940	0.942	0.945	0.947	0.949	0.952	0.954	0.956	0.958	0.959	0.961	0.963
Ver-MD	0.245	0.261	0.277	0.292	0.309	0.327	0.342	0.359	0.376	0.392	0.409	0.425	0.442
Ver-VA	0.221	0.236	0.252	0.268	0.284	0.300	0.316	0.333	0.350	0.366	0.383	0.399	0.416
Ver-WV	0.105	0.116	0.128	0.140	0.152	0.166	0.179	0.193	0.208	0.223	0.238	0.254	0.270
Ver-DE	0.202	0.216	0.231	0.247	0.262	0.279	0.295	0.311	0.328	0.344	0.361	0.377	0.394
Ver-PA	0.228	0.243	0.259	0.275	0.291	0.307	0.324	0.340	0.357	0.374	0.390	0.407	0.423
Ver-NJ	0.374	0.390	0.407	0.423	0.440	0.456	0.472	0.488	0.504	0.519	0.534	0.549	0.564
Ver-NE	0.152	0.165	0.179	0.193	0.208	0.223	0.238	0.264	0.269	0.286	0.302	0.318	0.335
Ver-NY	0.261	0.277	0.293	0.309	0.326	0.342	0.359	0.376	0.392	0.409	0.425	0.442	0.458
Nev. Bell	0.139	0.151	0.164	0.178	0.192	0.207	0.222	0.237	0.252	0.268	0.284	0.301	0.317
Pac. Bell	0.302	0.319	0.335	0.352	0.368	0.385	0.402	0.418	0.435	0.451	0.467	0.483	0.499
SW Bell	0.156	0.170	0.183	0.198	0.212	0.227	0.243	0.258	0.274	0.290	0.307	0.323	0.340
Cinc. Bell	0.250	0.266	0.282	0.298	0.315	0.331	0.348	0.364	0.381	0.397	0.414	0.430	0.447
SNE	0.159	0.173	0.187	0.201	0.216	0.231	0.246	0.262	0.278	0.294	0.311	0.327	0.344
Centel-VA	0.072	0.081	0.091	0.101	0.112	0.123	0.135	0.148	0.160	0.174	0.188	0.202	0.217
Ver-CA	0.219	0.234	0.250	0.266	0.282	0.298	0.314	0.331	0.347	0.364	0.381	0.397	0.414
Ver-FL	0.164	0.178	0.192	0.207	0.222	0.237	0.252	0.268	0.284	0.301	0.317	0.334	0.350
Ver-HI	0.174	0.188	0.202	0.217	0.232	0.248	0.263	0.279	0.296	0.312	0.328	0.345	0.362
Ver-NO	0.052	0.059	0.067	0.075	0.084	0.094	0.105	0.116	0.127	0.139	0.152	0.165	0.179
Ver-NW	0.087	0.096	0.107	0.118	0.130	0.142	0.155	0.168	0.182	0.196	0.211	0.226	0.241
Ver-SO	0.067	0.075	0.084	0.094	0.104	0.116	0.127	0.139	0.152	0.165	0.179	0.193	0.207
PR Telco	0.083	0.093	0.103	0.114	0.126	0.138	0.150	0.163	0.177	0.191	0.206	0.220	0.236
UT-IN	0.057	0.064	0.073	0.081	0.091	0.102	0.112	0.124	0.136	0.148	0.161	0.175	0.189
UT-OH	0.054	0.061	0.069	0.078	0.087	0.097	0.107	0.118	0.130	0.142	0.155	0.169	0.182
UT-PA	0.044	0.051	0.058	0.066	0.074	0.083	0.093	0.103	0.114	0.126	0.138	0.150	0.163

Table A6 – Efficiency Scores-Input Distance Function- Normal/Half Normal model- with Inefficiency Effects

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Bell-IL	0.908	0.916	0.947	0.914	0.919	0.930	0.943	0.937.	0.952	0.955	0.959	0.962	0.959
Bell-IN	0.851	0.838	0.852	0.850	0.898	0.922	0.926	0.934	0.956	0.956	0.958	0.960	0.959
Bell-MI	0.800	0.814	0.846	0.855	0.852	0.846	0.922	0.896	0.929	0.925	0.920	0.940	0.928
Bell-OH	0.874	0.874	0.887	0.908	0.907	0.920	0.933	0.932	0.951	0.951	0.952	0.959	0.951
Bell-WI	0.800	0.821	0.794	0.816	0.823	0.856	0.898	0.921	0.937	0.938	0.937	0.944	0.941
Ver-DC	0.878	0.860	0.939	0.930	0.937	0.936	0.944	0.924	0.921	0.935	0.942	0.934	0.937
Ver-MD	0.838	0.861	0.906	0.894	0.918	0.923	0.934	0.944	0.948	0.953	0.959	0.963	0.964
Ver-VA	0.822	0.825	0.899	0.885	0.913	0.910	0.913	0.926	0.933	0.941	0.948	0.954	0.955
Ver-WV	0.668	0.753	0.819	0.832	0.877	0.866	0.897	0.926	0.937	0.954	0.957	0.961	0.963
Ver-DE	0.728	0.710	0.874	0.887	0.900	0.904	0.919	0.935	0.951	0.961	0.967	0.967	0.963
Ver-PA	0.840	0.836	0.908	0.899	0.908	0.915	0.924	0.931	0.941	0.951	0.956	0.961	0.957
Ver-NJ	0.830	0.760	0.875	0.887	0.885	0.901	0.937	0.916	0.937	0.945	0.960	0.965	0.966
Ver-NE	0.827	0.798	0.814	0.802	0.850	0.883	0.814	0.881	0.816	0.830	0.904	0.935	0.935
Ver-NY	0.670	0.692	0.806	0.785	0.865	0.875	0.838	0.862	0.904	0.909	0.913	0.947	0.951
Nev. Bell	0.811	0.784	0.839	0.847	0.868	0.875	0.936	0.937	0.933	0.944	0.935	0.961	0.935
Pac. Bell	0.813	0.840	0.882	0.957	0.920	0.934	0.934	0.938	0.959	0.951	0.959	0.953	0.949
SW Bell	0.800	0.861	0.878	0.891	0.912	0.899	0.914	0.923	0.947	0.953	0.956	0.953	0.955
Cinc. Bell	0.760	0.744	0.710	0.783	0.844	0.888	0.916	0.875	0.945	0.962	0.947	0.955	0.958
SNE	0.641	0.680	0.719	0.701	0.834	0.860	0.854	0.859	0.924	0.925	0.918	0.861	0.843
Centel-VA	0.892	0.870	0.873	0.869	0.896	0.912	0.907	0.930	0.930	0.949	0.941	0.910	0.930
Ver-CA	0.914	0.864	0.876	0.894	0.935	0.929	0.924	0.932	0.940	0.944	0.951	0.964	0.974
Ver-FL	0.485	0.546	0.785	0.879	0.924	0.926	0.536	0.950	0.955	0.965	0.958	0.967	0.955
Ver-HI	0.728	0.929	0.862	0.882	0.897	0..889	0.861	0.870	0.903	0.937	0.932	0.959	0.968
Ver-NO	0.849	0.810	0.846	0.798	0.859	0.867	0.873	0.868	0.901	0.925	0.914	0.958	0.969
Ver-NW	0.696	0.285	0.843	0.914	0.881	0.864	0.890	0.874	0.933	0.947	0.949	0.969	0.964
Ver-SO	0.586	0.611	0.842	0.861	0.873	0.882	0.894	0.835	0.921	0.933	0.942	0.957	0.972
PR Telco	0.388	0.785	0.780	0.850	0.892	0.957	0.897	0.882	0.909	0.922	0.942	0.944	0.958
UT-IN	0.918	0.912	0.914	0.905	0.887	0.836	0.860	0.889	0.957	0.952	0.954	0.926	0.953
UT-OH	0.646	0.634	0.883	0.913	0.905	0.905	0.918	0.925	0.961	0.962	0.958	0.927	0.943
UT-PA	0.669	0.505	0.880	0.890	0.845	0.801	0.861	0.868	0.953	0.955	0.932	0.885	0.932