GRIPS Research Report Series I-2000-0004

DEA AS APPLIED TO PRICE-CAP SETTINGS OF NTT

By

Kaoru Tone

National Graduate Institute for Policy Studies
2-2 Wakamatsu-cho, Shinjuku-ku, Tokyo 162-8677, Japan
tone@grips.ac.jp

First version: November 1, 2000

GRIPS

NATIONAL GRADUATE INSTITUTE FOR POLICY STUDIES

DEA AS APPLIED TO PRICE-CAP SETTINGS OF NTT

By

Kaoru Tone

National Graduate Institute for Policy Studies
2-2 Wakamatsu-cho, Shinjuku-ku, Tokyo 162-8766, Japan.
tone@grips.ac.jp

First version: November 1, 2000

Any comments on this paper are welcomed. The views in this paper are solely those of the author but not necessarily indicative of those of the Ministry of Posts and Telecommunications, Japan (MPT) and Nippon Telegram and Telephone Company (NTT). Support from the MPT for this study was greatly appreciated. This study was also supported by Grant-in-Aid for Scientific Research (C), Japan Society for the Promotion of Science.

DEA AS APPLIED TO PRICE-CAP SETTINGS OF NTT

Kaoru Tone
National Graduate Institute for Policy Studies *

Abstract

Price-settings of public utilities, e.g., telecommunications, electricity and water supply, are crucial societal matters. As a part of the deregulation promotion policy in Japan, the Ministry of Posts and Telecommunications (MPT) has set forth a price-cap system for telecommunication utilities that starts from October 1, 2000. This is the first instance in Japan where a price-cap system has been introduced to such an influential field as telecommunications. This paper describes how the cap was determined by referring to an analytical tool called Data Envelopment Analysis (DEA).
Keywords: DEA, price-cap, cost efficiency, telecommunications, X-efficiency, deregulation, public utilities

1. Introduction

As a part of the deregulation promotion projects of the Japanese Government, the Ministry of Posts and Telecommunications (MPT) has decided to abolish the sanction system for price settings in telecommunications industry and to shift to the price-cap system starting from October 1, 2000. Thus, it has become possible for telecommunication agents to set their prices within the ceilings determined by the price-cap only by notifying the Ministry. For the purpose of a smooth transition to the new system, the MPT

*2-2 Wakamatsu-cho, Shinjuku-ku, Tokyo 162-8766, Japan. tone@grips.ac.jp.

organized two committees for studying the price-cap system. One, chaired by Professor Horibe of Chuo University, examined possible schemes for the new price system during the year 1998 and the other, chaired by Professor (Emeritus) Okano of the University of Tokyo, studied the exact formulas for setting price-caps during fiscal 1999. As a member of the latter committee, the author of this paper engaged in the measurement of cost inefficiency of Nippon Telegraph and Telephone Company (NTT) by using Data Envelopment Analysis (DEA). NTT has monopolized the telecommunication system in Japan even after it had turned into a private enterprise in 1985 and was then reorganized into three companies: NTT East, NTT West and NTT Communications in 1999. Since the first two has had a large market share in the regional communications in Japan, the target of this study focuses eventually on NTT East and West.

In this paper, the author describes this price-cap setting procedure, putting emphasis on the application of DEA for measuring the cost inefficiency of NTT.

2. Price-cap System

The price settings of public utilities are a crucial societal matter. The price-cap system has been introduced in the U.K., U.S.A. and other countries for ceiling prices of telecommunications, electricity, water and so forth. When this system is applied to services under not sufficiently competitive environments, it complements market mechanisms, protects consumers' loss and eventually results in price reduction by giving an incentive for efficient operation among the enterprises concerned. This system has the following merits: (1) for consumers, at least a certain rate of price reduction is guaranteed and (2) for enterprises, they can set prices freely under the ceilings by notifying authorities like MPT and are not forced to reduce prices any more within a certain time period even when they get profits by efforts on their side.

There are at least two important factors for deciding the price-cap: the consumer price index (CPI) and the productivity progress index (X-efficiency). The former reflects the trend of consumer prices and the latter relates to price reductions due to advancement in productivity.

The basic formula for deciding the price index in the next year from the current one is as follows.

$$\text{New Price Index} = \text{Current Index} \times (1 + CPI - X). \tag{1}$$

Usually we can estimate the CPI from published statistics and the X-efficiency can be obtained by analyzing past performances of enterprises.

3. X-Efficiency

Assume that the update for the price index obtained by formula (1) continues for consecutive t years. Then, the revenue at the t-th year will be reduced to

$$R \times (1 + CPI - X)^t,$$

where R is the predicted revenue at the t-th year. We balance this value with the sum of cost (C) and reasonable profit (P), the latter including tax for profit, at the t-th year. Thus, we have a balance equation:

$$R \times (1 + CPI - X)^t = C + P. \tag{2}$$

Although we take a balance between cost and revenue at the end of t years, there are other schemes for this purpose, e.g., balancing cost and revenue throughout t years. However, the balance equation (2) is applied for our study. From this equation we have a formula for determining X-efficiency as,

$$X = 1 + CPI - \sqrt[t]{\frac{C + P}{R}}. \tag{3}$$

As will be mentioned later, we estimate C, P and R using past data and the medium-range management plan of NTT. The validity of the estimated cost (C) will be checked via DEA as follows.

4. Cost-Efficiency measured by DEA

DEA (Data Envelopment Analysis) is a data oriented non-parametric method that evaluates the relative efficiency of each object, called a DMU (Decision Making Unit), by linear programming technology. (See [2, 3] for details of

DEA.) Here we will describe briefly the cost-efficiency model of DEA. Suppose that there are n DMUs with m inputs and s outputs. We denote inputs and outputs of DMU_j by $\boldsymbol{x}_j = (x_{1j}, \ldots, x_{mj})^T$ and $\boldsymbol{y}_j = (y_{1j}, \ldots, y_{sj})^T$, respectively. The input and output data matrices X and Y are defined as

$$X = (\boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_n), \quad Y = (\boldsymbol{y}_1, \boldsymbol{y}_2, \ldots, \boldsymbol{y}_n).$$

Let the unit cost of input x_{ij} be c_{ij} and the corresponding cost vector be $\boldsymbol{c}_j = (c_{1j}, \ldots, c_{mj})$.

For each DMU_o $(o = 1, \ldots, n)$, we solve the following LP.

$$\begin{aligned} &\min \boldsymbol{c}_o \boldsymbol{x} \\ &\text{subject to } X\boldsymbol{\lambda} = \boldsymbol{x}, \quad Y\boldsymbol{\lambda} \geq \boldsymbol{y}_o, \quad \boldsymbol{\lambda} \geq \mathbf{0}. \end{aligned} \tag{4}$$

The objective of this LP is to find the minimum cost inputs mix in the production possibility set PPS, defined below, under the condition that the outputs of DMU_o are restricted to not less than the current outputs $\boldsymbol{y}_o$.

$$\text{PPS} = \{(\boldsymbol{x}, \boldsymbol{y}) |\ \boldsymbol{x} \geq X\boldsymbol{\lambda},\ \boldsymbol{y} \leq Y\boldsymbol{\lambda},\ \boldsymbol{\lambda} \geq \mathbf{0}\} \tag{5}$$

Let an optimal solution of this LP be $(\boldsymbol{x}^*, \boldsymbol{\lambda}^*)$. We define the cost-efficiency τ_o of DMU_o by

$$\text{Cost efficiency } (\tau_o) = \boldsymbol{c}_o \boldsymbol{x}^* / \boldsymbol{c}_o \boldsymbol{x}_o \tag{6}$$

Using the *technical efficiency* θ_o^C (the CCR-efficiency score measured under constant returns-to-scale assumption), the *allocative efficiency* α_o is defined as the ratio τ_o/θ_o^C. We now define the *scale efficiency* σ_o as the ratio θ_o^C/θ_o^V where θ_o^V is the *pure technical efficiency* (the BCC-efficiency score measured under variable returns-to-scale assumption).

Thus, we have a decomposition of cost efficiency as follows:

$$\text{Cost-efficiency } (\tau_o) = \theta_o^V \times \sigma_o \times \alpha_o \tag{7}$$

Later on we will employ regional adjustments of the cost-efficiency to take account of the scale factor of enterprises. For this purpose, we define *adjusted cost-efficiency* by dividing the cost efficiency by the scale efficiency as:

$$\text{Adjusted cost-efficiency } (\rho_o) = \tau_o/\sigma_o = \theta_o^V \times \alpha_o \tag{8}$$

As the right side indicates, this efficiency is equal to the product of the pure technical efficiency and the allocative efficiency.

5. Data and Results

We chose inputs and outputs of the NTT group enterprises referring to the preceding study on this subject by Asai and Nemoto [1]. We should note that in many aspects, this study benefited from their research.

We utilized data of five branches: Hokkaido, Tohoku, Tokyo, Kanto and Shin-Etu belonging to NTT East, and six branches: Hokuriku, Tokai, Kansai, Chugoku, Shikoku and Kyushu belonging to NTT West, for the period 1994-1997. Thus, we have 44 (= 11 branches $\times$ 4 years) DMUs for our study. The inputs, outputs and price factors are as follows:

Input(1): Labor = Number of employees at the end of the fiscal year.
Input(2): Capital = Real fixed assets for telecommunications excluding accounts for lands and buildings.
Input(3): Material = Number of subscribers for subscriber line and ISDN (integrated services digital network).
Output(1): Voice transmission = Communication hours utilized by subscriber line and ISDN (including those links to outside agencies).
Output(2): Lease = Number of leased lines (in terms of equivalent subscriber lines and including those for outside leased line agencies).
Cost(1): Labor = Real yearly labor costs divided by the number of employees.
Cost(2): Capital = (Price index for investment) $\times$ (Interest rate of government-guaranteed bonds + Amount of depreciation for fixed assets related to the telecommunication business) / (Wholesale price index).
Cost(3): Material = Real material costs divided by the number of subscribers at the end of the fiscal year.

From these data, we obtained, for each DMU, four efficiency measures: technical (θ^C), pure technical (θ^V), cost (τ) and adjusted cost (ρ). Since constant returns to scale are assumed in the evaluation of technical efficiency, large scale branches, e.g., Tokyo and Kanto have high marks, while small ones, e.g., Hokuriku, Shin-Etu and Shikoku low marks, in the case of the telecommunications industry. Hence, an adjustment to the influence over efficiency due to scale factors is needed. In an effort to overcome this problem, several attempts have been made. As a typical example, technical efficiency has been often explained by other exogenous variables. However, Xue and Harker [5] pointed out that regression of DEA score by other raw data arises theoretically hard problems. So, we applied the scale efficiency obtained as the ratio of technical vs. pure technical efficiencies and utilized the (scale) adjusted cost efficiency (ρ) as the final measure. Table 1 exhibits the scale, cost, and adjusted cost efficiencies for each branch.

Table 1

As to the scale efficiency score, Hokuriku, Shikoku, Shin-Etu and Hokkaido have low values suggesting that they are located in scale-disadvantaged regions. The list of cost efficiency reveals that Tohoku, Shin-Etu, Hokkaido, Shikoku, Chugoku and Hokuriku have low marks in this order. After adjusting cost efficiency by scale, we find that Hokuriku and Shikoku's positions are considerably advanced, while Tohoku, Chugoku, Hokkaido and Shin-Etu still remain inferior even in scale-adjusted scores.

We calculated the scale-adjusted cost efficiency of NTT East and West by the following manner. We also obtained the average of the adjusted cost efficiency scores using cost of branches in NTT East (West) as weight. Table 2 exhibits the inefficiency (= 1− efficiency) of NTT East and West thus obtained.

Table 2

Although both companies have comparatively high levels of cost inefficiency (13.0% and 12.3% on average), it is observed that their efficiencies have advanced in 1997.

6. Cost Reduction Plan by NTT

On November 17, 1999, NTT East and West worked out and announced the "Medium Range Management Improvement Plan." In this plan they tried hard to reduce labor costs, capital investment, material costs and cosigned works consecutively through three years from 2000 to 2002. If this plan is successfully executed, they will have estimated total cost reduction at the fiscal 2002 year as follows: NTT East will reduce costs by about 160 billion yen and NTT West by about 190 billion yen. Adding the cost reductions already attained to these figures, it would be possible for them to reduce costs by about 250 billion yen for NTT East and 300 billion yen for NTT

West. These figures are equivalent to 8.7% of NTT East's current costs and 10.1% of NTT West's.

By looking into the adjusted cost inefficiencies scores in Table 2, we can conclude that the above cost reduction plans by the two NTTs are within the range of cost inefficiencies measured by the DEA cost model, and will be attainable by eliminating the cost inefficiencies of both companies.

7. Determination of Price-cap

The main objectives of this project were directed forwards the price cap of two services, e.g., the voice transmission and the leased line of NTT East and West. In order to determine the price-cap we first calculate X-efficiency by using equation (3) that contains CPI (consumer price index), C (cost), P (profit), R (revenue) and t (year) as parameters. For this purpose, we utilized the following values for the voice transmission (subscriber line and ISDN) of the NTT East case:

1. CPI=−0.3% (CPI for the fiscal 1999 and common to all cases)
2. t=3 years
3. R=1489.8 billion yen that was estimated by using several forecasting techniques, e.g., regression analysis and trend analysis.
4. C=1330.8 billion yen that came from the Medium Range Management Improvement Plan by NTT and is ascertained as attainable by DEA as mentioned above.
5. P=84.3 billion yen that was determined by referring to borrowed capital costs, stockholders' equity owned capital costs, average profit rate of owned capitals in major industries, interest rate of government bond, and NTT West's profit.

Putting these values in (3), we have

$$X = 1.9\% \quad \text{(for the voice transmission service of NTT East.)} \qquad (9)$$

Further, recourse to equation (1) gives, for the voice transmission service of NTT East,

$$\text{New Price Index} = 100 \times (1 + CPI - X) = 97.8\%. \qquad (10)$$

In the same way, we calculated the price index for the leased line service of NTT East and obtained the new price index 97.6% for this service.

In determining these indices we took special care to ensure that the two companies, East and West, could choose the same price system if they wish. This reflects the view that it is not advisable for the two companies to develop largely different price levels in a comparatively short period since their separation in 1997. Thus, it turns out that the same price-cap was employed for the two companies.

The price-cap thus obtained was approved by the Minister of Posts and Telecommunications and noticed NTT East and West on June 21, 2000.

In correspondence to this notice, NTT East and West set up their new price system on August 31, 2000 and this system is scheduled to come into effect from October 1, 2000.

The contents of the new price system have the following characteristics: (1) the two companies employed the same price level, (2) they reduced the price gap due to distance differentials and (3) they set a special low rate price for internet service for educational usage.

Table 3 exhibits a summary of the prices employed by NTT East and West, and the price-caps proposed by MPT. It may be observed that both company chose prices nearly equal to the price-caps. Although the price system is the same between the two, the differences in the indices in Table 3 are caused by the difference in the traffic structures of NTT East and West.

Table 3

8. Concluding Remarks

In this paper we have described the process of price-cap settings for NTT East and West, putting emphasis on DEA usage. It is very rare for an analytical tool like DEA to be referred to in decision-making by Japanese government. (In the U.K., we see an example in an OFTEL study [4].)

The author would like to point out several points of interest learned through this study.

1. Operations research/management science technology deals with a model of the actual world or business, and hence it has limits as to the ranges

to which it can be applied. Concerning the DEA cost model, it is based on the assumption that the substitutions among inputs are possible, e.g., substitution between labor and capital. This substitution may be possibly observed as a long range shift, but it is difficult to realize in a short time period. However, it is very interesting to observe that the cost reductions proposed in the Medium Range Management Improvement Plan of NTT turned out to be situated within the range of results by the DEA cost model. This will help NTT to confirm the feasibility of their plan.

2. This study utilized data gathered only within NTT. Thus, each branch is compared with the best performers within NTT. In most cases, the best performers were among large-scale branches, e.g., Tokyo, Kanto and Kansai. However, we should extend the data set to include outer enterprises or foreign equivalents. In this study, due to lack of data, the difference between business styles and the accounting systems, we could not execute such important comparisons. This should be a subject for future research.

3. In this study, the price and the demand were predicted independently. However, in view of the rapid diffusion of Internet communications and cellular phones in recent days, we need to consider the price-elasticity of demand along with the trend analysis in any future demand forecast. If we assume 10% increase in the revenue (R) in (3), then the price-cap reduces to 95.2% in the case of the voice service of NTT East.

4. The price-cap system plays a crucial role in developing information technologies in Japan. So, it is strongly recommended that the updating of price-caps be repeated periodically by taking account of new data on revenue, costs and profit.

References

[1] Asai, S. and Nemoto, J., "Measuring the Efficiency of Regional Telecommunication Enterprises," (in Japanese) Discussion paper No. 1998-08, Institute for Posts and Telecommunications Policy, 1998.

[2] Charnes, A., Cooper W.W. and Rhodes, E., "Measuring the Efficiency of Decision Making Units," *European Journal of Operational Research,* 2(6), 429-444, 1978.

[3] Cooper, W.W., Seiford, L.M. and Tone, K., *Data Envelopment Analysis — A Comprehensive Text with Models, Applications, References and DEA-Solver Software,* Kluwer Academic Publishers, 1999.

[4] NERA, *BT Comparative Efficiency Study*, Report prepared for Office of Telecommunications, UK, December 1995.

[5] Xue, M. and Harker, P.T., "Overcoming the Inherent Dependency of DEA Scores: A Bootstrap Approach," Discussion paper, Wharton Scool, University of Pennsylvania, April 1999.

Table 1: Efficiency Scores through 1994-1997

	Scale Efficiency				
	1994	1995	1996	1997	Average
Tokyo	0.995	0.994	0.997	1.000	0.997
Kanto	0.997	0.998	0.999	1.000	0.999
Shin-Etu	0.860	0.887	0.894	0.897	0.885
Tokai	0.970	0.975	0.978	0.979	0.976
Hokuriku	0.778	0.792	0.828	0.853	0.813
Kansai	0.997	0.997	0.998	0.998	0.998
Chugoku	0.939	0.950	0.954	0.954	0.949
Shikoku	0.858	0.885	0.893	0.896	0.883
Kyushu	0.980	0.980	0.980	0.982	0.981
Tohoku	0.930	0.933	0.939	0.942	0.936
Hokkaido	0.895	0.898	0.913	0.936	0.911
	Cost Efficiency				
	1994	1995	1996	1997	Average
Tokyo	0.848	0.825	0.887	1.000	0.890
Kanto	0.943	0.922	0.945	1.000	0.953
Shin-Etu	0.644	0.682	0.723	0.770	0.705
Tokai	0.910	0.892	0.916	0.964	0.921
Hokuriku	0.733	0.760	0.802	0.839	0.784
Kansai	0.915	0.880	0.886	0.937	0.905
Chugoku	0.717	0.724	0.760	0.797	0.750
Shikoku	0.690	0.728	0.767	0.805	0.748
Kyushu	0.771	0.771	0.807	0.845	0.799
Tohoku	0.622	0.641	0.677	0.717	0.664
Hokkaido	0.681	0.688	0.729	0.779	0.719
	Adjusted Cost Efficiency				
	1994	1995	1996	1997	Average
Tokyo	0.852	0.830	0.890	1.000	0.893
Kanto	0.946	0.924	0.946	1.000	0.954
Shin-Etu	0.749	0.769	0.809	0.858	0.796
Tokai	0.938	0.915	0.937	0.985	0.944
Hokuriku	0.942	0.960	0.969	0.984	0.963
Kansai	0.918	0.883	0.888	0.939	0.907
Chugoku	0.764	0.762	0.797	0.835	0.789
Shikoku	0.804	0.823	0.859	0.898	0.846
Kyushu	0.787	0.787	0.823	0.860	0.814
Tohoku	0.669	0.687	0.721	0.761	0.709
Hokkaido	0.761	0.766	0.798	0.832	0.789

Table 2: Adjusted Cost-inefficiency through 1994-1997 (%)

	1994	1995	1996	1997	Average
NTT East	15.9	16.8	13.0	6.5	13.0
NTT West	13.4	14.8	12.6	8.3	12.3

Table 3: Price-cap Indices vs. New NTT Indices

	Voice		Leased line	
	Price-cap	NTT	Price-cap	NTT
East	97.8%	97.4%	97.6%	95.8%
West	97.8%	97.8%	97.6%	96.3%