Causes of inefficiency in Japanese railways : Application of DEA for managers and policymakers

Jitsuzumi, Toshiya
Faculty of Economics, Kyushu University

Nakamura, Akihiro
Faculty of Economics, Tezukayama University

https://hdl.handle.net/2324/26065

出版情報：Socio-Economic Planning Sciences. 44 (3), pp.161-173, 2010-09. Elsevier
バージョン：

Causes of inefficiency in Japanese railways

Application of DEA for managers and policymakers

Toshiya Jitsuzumi[a,*], Akihiro Nakamura[b]

[a]*Faculty of Economics, Kyushu University, 6-19-1 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan*

[b]*Faculty of Economics, Tezukayama University, 7-1-1 Tezukayama, Nara 631-8501, Japan*

Submitted in June 2007, revised in April 2009

Abstract

Although railway services have been suffering financially due to modal shifts and aging populations, they have been and will be an essential component of the basic social infrastructure. Since railway firms generate positive externalities and are required to operate in predetermined licensed areas, governmental intervention/support may be justified in some cases. Indeed, there are many types of subsidies offered for railway operation in Japan; while some of these subsidies are meant for covering huge investments, others are used as compensation for regional disparities. However, thus far, there has been no attempt made to analyze the reasons for the underperformance of the railway services; in other words, it is unclear whether this underperformance can be attributed to exogenous and uncontrollable causes or whether it can be understood to be the result of endogenous causes and hence capable of being handled by managers. Therefore, the optimal degree of intervention is not satisfactorily known. In this article, we propose a method based on data envelopment analysis (DEA) to analyze the causes of inefficiency in Japanese railway operations as well as to calculate the optimal subsidy that compensates for the practical lack of discretion for location change. This method was applied to 53 Japanese railway operators; as a result, we derived several characteristics in relation to the inefficiency of Japanese railway operations and found an optimal subsidy for them.

Keywords: Data envelopment analysis, Japanese railways, Efficiency, Optimal subsidy

[*]Corresponding author. Fax: +81-92-642-2495.

E-mail addresses: jitsuzum@en.kyushu-u.ac.jp (T. Jitsuzumi), akihiro@tezukayama-u.ac.jp (A. Nakamura)

1. INTRODUCTION

Currently, there are 206 firms in Japan that offer railway services. In 2002, these operators used 27,517 kilometers of railway tracks and carried 21.56 billion passengers. Since these firms provide basic transportation for local residents, they have for long been considered as an element of social infrastructure in which both national and municipal governments should be deeply involved. It is true that Japanese railways have recently been losing their relative importance due to changing conditions,[1] especially in relation to freight services where they currently handle only 4% of the country's total freight tonnage; however, they are still expected to play a significant role in passenger services for some time to come. In reality, Japanese railways have continued to carry 27% of all passengers, including 76.1% of mass-transit passengers.[2] In downtown Tokyo or other central business districts where traffic congestion is commonly observed, the railways remain a notably reliable form of transport.[3] Moreover, regarding freight services, the Ministry of Land, Infrastructure and Transport (MLIT) plans to expand the role played by railway services in future freight transport; this is partly because of the railways' positive environmental performance (e.g., reduced CO_2 and NOx emissions compared to motor traffic). Thus, it appears that Japanese railways will continue to satisfy the transportation demand and also possibly remain important both for local residents and for the environment.

Even if railway firms are socially desirable, they cannot survive unless they earn consistent operating profits. Since they generate positive externalities and are required to continue operation in predetermined locations through licensing regulation, intervention/support from governments may be justified in some cases. In fact, despite the huge national deficit, in cooperation with Japan Railway Construction, Transportation and Technology Agency

---

[1] Exogenous factors such as modal shifts have caused many local Japanese railway firms to suffer significant financial losses. The Local Railway Business Study Group (LRBSG) [1] has cast some doubt on the viability of railway providers in the near future, identifying at least four factors as having a negative impact (modal shifts; acceleration of demographic aging; deflation; and financial deficits of national and municipal governments).

[2] This is based on Asahi Shimbun Publishing Co. [2] and the information provided on the MLIT website (http://toukei.mlit.go.jp/16/handbook/001youran.1-1hyou.pdf).

[3] Various traffic control initiatives, such as off-peak commuting, "no car" days, and working from home, have for long been implemented in Japan; however, the situation has not improved significantly. Mitomo and Jitsuzumi [3] estimate the number of Japanese "teleworkers" and summarize the impact of this activity.

(JRTT),[4] the MLIT spent 224.1 billion yen on railway support in 2004. Table 1 shows examples of railway subsidy schemes. In addition, many municipal governments have extended substantial support to local railway firms in order to keep them from bankruptcy. Some of this support is offered directly in order to ensure that operating deficits are met; other supports, on the other hand, are indirect and offered with the intention of helping firms attract more customers (e.g., via provision of station-front parking lots or short-haul commuter bus services linking neighboring communities).

However, to date, the optimal degree of intervention is not satisfactorily known. We believe that until the degree of influence of the external/uncontrollable causes on the railway's operation is determined, the optimal amount of subsidy will remain unclear. Any support provided to compensate for the financial hardships derived from endogenous or managerially controllable factors will convey a misleading message to railway managers. This paper aims to analyze variations in the causes of inefficiency among Japanese railway firms and to propose a method to calculate the optimal subsidy size for individual railway firms. It is believed that the analysis of variations in the causes of inefficiency and the new method of calculation will be beneficial for managers and policymakers, respectively. At this point, it is important to mention that our proposed subsidy is designed to compensate for the financial burden caused, not by first-best pricing under the diminishing average cost structure, but by regional disparities that may require railway operators in rural areas to bear additional costs.[5] Once a community decides to maintain railways as a key infrastructure for its economic and social activities, offering financial support to a rural firm in order to compensate for the unfavorable operating condition of the community appears to be a sensible decision from the economic perspective.

The remainder of this paper is organized as follows. Section 2 explains our analytical framework. Section 3 details the data used in the study, and Section 4 provides a brief explanation of the DEA method. Section 5 includes our empirical findings, and Section 6 presents the conclusion.

---

[4] JRTT is an independent agency that was founded in 2003 by integrating Japan Railway Construction Public Corporation and Corporation for Advanced Transport and Technology; it offers support for new line construction and R&D.

[5] In order to calculate the optimal subsidy as compensation for the decreasing average cost structure, we need to estimate the cost functions of railway operation to determine the efficient amount of expenditures that is not covered by marginal cost pricing. Such estimations have already been made by several researchers, including Mizutani [4]. Thus, if there exists a diminishing average cost structure and if operators employ marginal cost pricing, our optimal subsidy will not be sufficient to cover the total financial loss.

Table 1: Subsidies and assistance offered to Japanese railways

Name of subsidy	Application/ Type	Enterprise who gets subsidy	Amount of subsidy/Incidence
Subway construction subsidy	Construction of subway/ Capital subsidy (but essentially operating subsidy)	Eidan and public or semi-public subways (local government) <urban area>	70% of construction cost/ National & local government 35% each
New town line subsidy	Construction of new town commuter line/ Capital subsidy (but essentially operating subsidy)	Local government and semi-public sector <urban area>	36% of construction cost/ National & local government 18% each
Interest payment assistance	New lines or expanded lines/ Capital subsidy	Private railways in large metropolitan areas (but lines must be approved by government)	Repayment over 5% interest rate/ National & local government equally/ The year after construction
Arterial rail line subsidy	Conversion from freight service to passenger service, lowering truck, and speeding up etc./ Capital subsidy	Semi-public contractor <urban area>	Up to 40% of construction cost/ National & local government 20% each
Station vicinities development subsidy	Improvement of railway station facilities/ Capital subsidy	Semi-public contractor <urban area>	A part of cost/ Up to 25% of cost from national government. At least equivalent subsidy from local government.
Deficit subsidy (until 1997)	Timeworn local line and necessary to operate for community/ Operating subsidy	Small to medium-sized local railways (mainly rural areas)	Annual operating deficit/ National & local government equally
Modernization subsidy	Old-fashioned railways/ Capital (equipment) subsidy	Small to medium-sized local railways	20% of equipment improvement cost/ National & local government equally or 10% of cost by only national government
Grade crossing subsidy	Improvement of crossing facilities/ Capital (facility) subsidy	Small to medium-sized local railways	83.3% of improvement cost (66.7% for a company which yields profit)/ National 50% (33.3%) & local government 33.3% (33.3%)
Subsidy for privatized lines	Privatized line from JNR etc/ Operating subsidy	Small to medium-sized local railways (mainly rural areas)	40% of ordinary deficit/ National government
Equipment subsidy for local new line (until 2001)	Equipment (car etc)/ Capital (equipment) subsidy	Small to medium-sized local railways	A part of equipment cost (10 million yen per route-km limit)/ National government
Disaster restoration subsidy	Post-disaster restoration/ Capital subsidy	Railways	50% of restoration cost/ National & local government 25% each
Public transportation subsidy: LRT	Light Rail Transit system/ Capital subsidy	Railways	50% of equipment cost/ National & local government equally
Public transportation subsidy: IC card	LRT car, LRT system, IC card system/ Capital subsidy	IC card consortium	A part of system install cost/ National government pays 33.3% or the equivalent amount of local government, whichever is smaller.
Barrier-free facility subsidy	Installation of barrier-free facilities/ Capital subsidy	Railway (except Eidan & other public subway)	Up to 66.6% of equipment cost/ National &local government equally (National government less than equal to local government)

Source: Adapted from Mizutani [5, pp.31-32, Table 2.6.1], by using the data from ITPS [6, 7] and the MLIT website.

2. ANALYTICAL FRAMEWORK

In order to refrain from offering excessive support (and thus hindering private sector incentives) or very little support (and thus jeopardizing the long-term survival of the railways), we need to analyze the current operation to determine the internal and external sources of operational inefficiencies. In order to be optimal, we need to ensure a subsidy level that is just high enough to compensate for the external causes, which include the community's request to continue railway operations in the designated area or the practical lack of discretion for location change to seek more profitable operations. In this study, we propose a DEA approach in order to differentiate internal or intrinsic inefficiency factors from external or environmental-based ones, utilizing the analytical framework originally proposed by Nakamura and Jitsuzumi [8].

Before constructing the analytical model, we need to define an appropriate "outcome" for railway operations.

Hensher et al. [9] identified the three key factors — productivity, profitability, and rate of return on assets (ROA)—that indicate the success of a business. According to Preston [10], since Japanese railway firms are generally involved in both transport and real-estate development, with their profits coming mainly from property development and related commercial development, the sole reliance on profitability figures can be misleading. Therefore, in this analysis, the authors mainly focus on productivity or operational efficiency, not on profitability or ROA.

Moreover, in order to explicitly reflect the social importance of the railways, we include their impact on surrounding communities as an "externality" outcome. This approach is employed in response to that adopted by Nakajima and Fukui [11], who measured the total factor productivity for major Japanese railway firms and pointed out that productivity should be measured by taking into consideration both qualitative aspects and externality issues.

In this article, we employ the following production process of the railway business (Figure 1). Here, it is assumed that railway businesses use fixed asset, staff, and related operating expenditures as inputs, and turn them into two outputs, which are passenger service and externalities on surrounding communities. In addition, the whole process is influenced by environmental or uncontrollable factors. In this article, we employed transportation density as a primary uncontrollable factor; which will be explained later in Section 4.

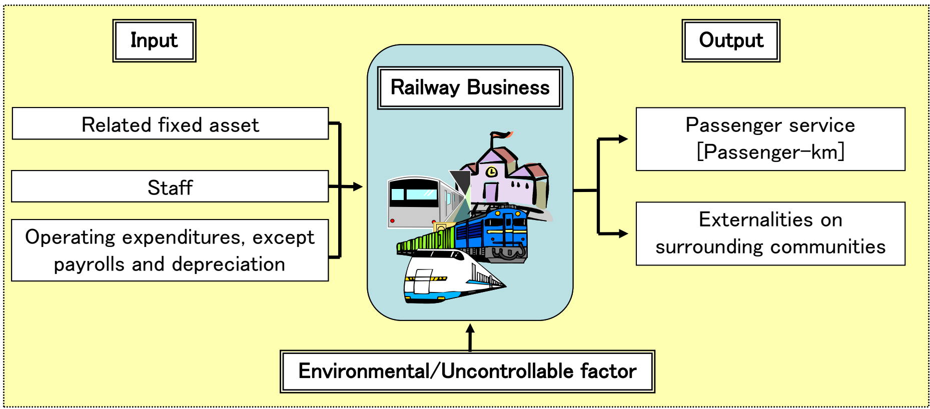


Figure 1: Projected production process of the railway business

3. DATA

As research samples for our study, we observed railway enterprises located in the Tokyo metropolitan area (large city), Kyushu (mostly countryside), and Kinki (includes large cities as well as countryside regions). Financial and operational data for 57 firms from 1998 to 2003 were collected from the Annual Statistics of Railway [12], and corresponding geographic and demographic data were gathered from Minryoku CD-ROM [2]. The geographic and demographic data, as well as the passenger transport share of mass transit, of each area are summarized in Table 2. The Tokyo metropolitan area is the most populated region in Japan and includes 7 prefectures (Chiba, Gunma, Ibaraki, Kanagawa, Saitama, Tochigi, and Yamanashi), in addition to Tokyo itself. From the viewpoint of the transportation demand, the Tokyo metropolitan area is the largest region in Japan and most of its transportation demand is satisfied by railway firms, possibly due to the rich availability of public transportation facilities and traffic congestion in city centers. Kinki is the second most populous region and consists of the following 7 prefectures: Hyogo, Kyoto, Mie, Nara, Osaka, Shiga, and Wakayama. The profiles of Kinki's transportation needs are similar to those of transportation needs in the Tokyo metropolitan area. Kyushu is located in the southwest part of Japan and consists of the following 7 prefectures: Fukuoka, Kagoshima, Kumamoto, Miyazaki, Nagasaki, Oita, and Saga. The transportation demand in this region is not as high as that in the Tokyo metropolitan area or Kinki, and less than half of Kyushu's transportation demand is met by the railway sector.

Table 2: Tokyo metropolitan, Kinki, and Kyushu areas

As of year 2000	Tokyo Metro. Area	Kinki Area	Kyushu Area	Whole Japan
Area (km^2)	36,887	33,110	42,165	377,873
Habitable area	19,077 (51.7%)	10,486 (31.7%)	15,287 (36.3%)	126,325 (33.4%)
Area of DID	3,956 (10.7%)	2,212 (6.7%)	1,225 (2.9%)	12,457 (3.3%)
Population	41,321,883	22,712,924	13,445,561	126,925,843
Daytime population	41,250,682 (99.8%)	22,636,324 (99.7%)	13,424,955 (99.8%)	
Population in DID	32,396,140 (78.4%)	17,352,468 (76.4%)	6,947,789 (51.7%)	82,809,682 (65.2%)
Area GDP (billion yen)	185,541	90,708	44,566	509,702
Area GDP p.c. (thousand yen)	4,490	3,994	3,315	4,016
Taxable income (billion yen)	71,631	33,556	15,582	188,149
Taxable income p.c. (thousand yen)	1,733	1,477	1,159	1,482
Length of road (km)	255,138	126,744	149,997	1,159,723
Share of paved road	73.6%	83.0%	86.2%	76.4%
Annual trips of public transportation system (thousands)	15,798,418	6,220,543	1,402,578	28,181,542
Railroad	13,337,375 (84.4%)	5,014,242 (80.6%)	613,791 (43.8%)	21,453,359 (76.1%)
Bus	2,433,361 (15.4%)	1,194,407 (19.2%)	770,700 (54.9%)	6,635,255 (23.5%)
Air	27,682 (0.2%)	11,894 (0.2%)	18,087 (1.3%)	92,928 (0.3%)
Annual trips per capita	383.0	274.8	104.5	222.0
Railroad	323.3	221.5	45.7	169.0
Bus	59.0	52.8	57.4	52.3
Air	0.7	0.5	1.3	0.7

Note 1: "p.c." = per capita, and "DID" = Densely-Inhabited District
Note 2: "Annual trips per capita" is "annual trips" divided by "daytime population."

Tokyo metropolitan, Kinki, and Kyushu areas have 54, 41, and 18 railway enterprises, respectively. However, these numbers include firms without data as well as firms that adopt different forms of railway services technology, such as monorails, trams, subways, cable cars, and light rail transits (LRTs).[6] While some operators carry only

[6] LRT is a form of tramcar system that generally employs electric rail cars on private rights of way or sometimes on streets.

passengers, some others offer freight services as well. Since the analytical approach adopted in this article is based on a peer comparison between samples, we may not be able to derive any meaningful information by comparing the operational efficiency of different rail technologies. Thus, we consider 53 passenger rail operators as samples for further analysis; of these, 25 are located in the Tokyo metropolitan area; 19, in Kinki; and 9, in Kyushu. The data of “fixed asset” is a year end monetary value of the fixed assets used for railway operation, and the data of “operating expenditure” does not include labor cost, tax, and depreciations. The number of the employees both in the railway operation section and in the headquarters is used as a staff input[7]. With respect to an uncontrollable factor, we propose transportation density, which is calculated as passenger kilometer divided by the length of operating lines. For externalities, we assume that the impact of railway services will be reflected in the general economic activity of the surrounding region; thus, we take into account the relative annual growth rate of per capita taxable income as a proxy for economic activity. We consider the average of the annual growth rate of the per capita taxable income index of the areas with no rail services as a baseline figure and then calculate the externality index for each railway company by comparing the annual growth rate of the service area with the baseline. In other words, when the index is more than 100, the region has more general economic activity than the average of areas with no rail services. On the other hand, an index of less than 100 may indicate a “straw” phenomenon in which railways enable the movement of economic and social activities from small communities to large cities. In order to evaluate inefficiency components in monetary terms, we need the unit cost information for each input factor: unit cost for fixed asset is obtained as depreciation cost divided by the value of fixed assets, unit cost for staff as labor cost divided by the number of staff, and unit cost for operating expenditures is set to unity.

The data for individual samples as of 2003 is presented in Table 3.

[7] The authors understand that this staff input is at most a good proxy of true labor input; however, uniform statistics on labor hours was not available for sample firms.

Table 3: Basic data of sample firms as of 2003

			Output		Input			Unit Cost		Uncontrollable
Area	Control	Company Name	Passenger-km (,000km)	Externality	Fixed asset (million yen)	Employee	Operating expenditure (,000yen)	Fixed asset	Employee	Transportation density (,000 person)
Tokyo metropolitan area	private	Choshi	2,393	100.8	563,177	23	39,615	0.0181	4,703.6	373.9
		Enoshima	49,261	99.1	5,071,294	146	473,145	0.0699	7,783.0	4,926.1
		Fujikyu	32,636	98.8	2,810,999	72	439,525	0.0542	7,262.7	1,226.9
		Ibaraki	6,753	98.3	730,525	29	56,254	0.0777	5,057.7	472.2
		Jomo	20,285	100.0	374,239	64	184,436	0.0476	5,945.6	798.6
		Joshin	33,878	99.8	979,610	84	222,776	0.0340	5,552.1	1,005.3
		Kanto	100,780	100.0	6,496,655	226	472,116	0.0725	6,907.7	1,812.6
		Kashima	6,184	102.2	440,866	31	72,219	0.0488	6,157.7	227.4
		Keihin	6,212,774	101.2	247,711,710	1,756	21,742,655	0.0647	11,520.3	71,411.2
		Keio	7,154,930	101.3	191,518,322	2,016	20,926,760	0.0686	12,363.5	84,473.8
		Keisei	3,461,141	101.5	194,404,407	1,918	12,819,606	0.0466	10,426.1	33,800.2
		Kominato	22,557	100.6	653,819	81	104,832	0.0491	5,680.0	576.9
		Odakyu	10,499,579	101.0	452,892,668	3,320	22,994,557	0.0518	11,026.1	87,133.4
		Sagami	2,620,202	100.2	121,232,047	1,101	6,201,876	0.0602	10,932.4	72,986.1
		Seibu	8,724,909	101.6	352,909,676	3,224	23,264,198	0.0635	10,272.7	49,404.9
		Shin-Keisei	724,155	100.2	17,189,713	482	2,861,985	0.0850	10,352.1	27,326.6
		Soubu-Nagareyama	19,995	100.0	701,601	72	125,918	0.0360	5,670.8	3,507.9
		Tokyu	9,476,929	101.3	434,573,395	2,671	59,153,395	0.0582	12,072.5	94,674.6
	semi-public	Hokusou	422,082	101.6	102,262,688	280	3,463,266	0.0223	7,517.7	13,067.6
		Isumi	6,269	99.7	71,054	31	88,163	0.1366	5,234.1	233.9
		Moka	20,590	100.6	53,833	53	191,682	0.1431	4,032.8	491.4
		Tokyo rinkai	245,898	101.8	266,544,418	237	2,365,362	0.0288	6,922.6	20,155.6
		Toyo	406,168	100.3	278,618,953	258	1,834,939	0.0204	6,878.3	25,072.1
		Watarase	11,257	99.5	59,049	56	168,789	0.0889	4,604.8	255.3
		Yagan	10,779	95.7	256,534	47	209,313	0.0673	5,968.0	351.1
Kinki area	private	Eizan	28,876	100.7	3,555,039	85	262,119	0.0492	6,780.0	2,005.3
		Hankyu	8,916,762	100.2	410,131,740	1,855	41,821,334	0.0313	12,887.6	60,865.3
		Hanshin	1,741,176	100.2	79,652,652	1,155	7,326,478	0.0590	8,486.9	38,607.0
		Hokushin	68,160	100.0	15,869,868	54	1,098,586	0.0473	2,712.4	9,088.0
		Keihan	4,365,263	99.9	214,124,867	2,381	11,327,368	0.0393	10,213.0	49,549.0
		Kintetsu	12,281,160	100.1	741,718,013	5,669	57,159,025	0.0284	9,283.4	21,406.9
		Kisyu	231	101.0	40,886	5	9,563	0.0700	3,342.2	85.6
		Kita-Osaka	258,182	100.4	13,885,963	151	1,467,193	0.0723	11,628.0	43,759.7
		Kobe	524,032	100.0	80,090,819	536	2,191,204	0.0373	6,828.4	7,529.2
		Mizuma	8,211	99.3	488,783	29	81,882	0.0461	4,782.5	1,492.9
		Nankai	3,930,025	99.9	366,213,687	2,659	16,744,863	0.0265	7,884.4	23,240.8
		Nose	170,713	99.0	27,391,095	78	1,160,649	0.0259	7,999.9	11,085.3
		Omi	30,929	99.3	3,866,125	86	359,503	0.0495	5,302.0	519.8
		San-yo	789,792	99.9	31,286,768	725	3,966,214	0.0676	8,615.2	11,218.6
	semi-public	Hojo	3,210	99.8	27,988	12	30,865	0.0771	4,969.5	236.0
		Kita-Kinki-Tango	44,047	100.1	2,398,889	156	996,754	0.0821	5,070.0	386.4
		Miki	820	99.8	193,938	12	21,198	0.0878	4,911.8	124.2
		Osaka-Toshi	468,576	99.4	20,695,922	311	2,323,887	0.0838	8,898.7	32,767.6
		Shigaraki	6,778	99.7	88,887	18	55,286	0.0942	5,681.1	461.1
Kyushu area	private	Chikuhou	42,408	98.9	1,722,980	79	495,274	0.0672	7,283.9	2,650.5
		Kumamoto	7,399	99.8	324,485	26	85,829	0.0847	4,541.8	564.8
		Nishi-nihon	1,745,032	100.3	66,005,323	966	6,232,303	0.0675	8,257.6	15,056.4
		Shimabara	34,476	99.8	5,074,081	136	200,021	0.0218	4,064.4	439.2
	semi-public	Amagi	8,735	100.2	174,372	28	72,432	0.1258	4,792.5	637.6
		Kumagawa	13,830	99.3	87,627	31	84,494	0.0850	3,654.6	557.7
		Matsuura	35,603	100.2	322,894	95	408,194	0.1265	3,932.8	379.6
		Minami-Aso	3,542	100.1	22,442	14	39,911	0.0944	3,914.4	200.1
		Takachiho	9,833	98.5	78,211	35	112,850	0.0916	3,536.1	196.7

4. DEA APPROACH[8]

The basic concept of DEA is to evaluate the comparative efficiency of a decision-making unit (DMU) by calculating the ratio between output and input. In this article, each observation, i.e., each combination of railway and year, is regarded as an individual DMU. The DEA method measures efficiency by estimating an empirical production frontier, fitting pieces of hyperplanes to envelop the observed input-output data.[9] The inefficiency of a

[8] For further details, refer to Cooper et al. [13].

[9] According to Banker et al. [14], the resulting piecewise linear production frontier of a DEA is more flexible in approximating the true production frontier than the so-called flexible translog parametric functional form.

DMU (i.e., a sample firm at a specific point in time) is measured by the distance from the point representing its observed input-output combination to the corresponding reference point on the production frontier.

Mathematically, DEA can be expressed as the linear programming problems (1) and (2), with inputs (x_1, $x_2 \ldots x_m$), outputs (y_1, $y_2 \ldots y_s$), a nonnegative vector ($\lambda = (\lambda_1, \cdots \lambda_n)^T$), and θ^* as the optimal solution for problem (1). Here, the superscript T indicates a vector transpose. If an optimal solution satisfies $\theta^* = 1$ and is zero slack $\left(\mathbf{s}^{-*} = \mathbf{0}, \mathbf{s}^{+*} = \mathbf{0}\right)$, then the particular DMU under study (DMUo) is defined as "efficient." If DMUo is not efficient, then several efficient DMUs are designated as a "reference set" and the θ^* of DMUo is calculated based on the distance between DMUo and a "projected DMUo," which is a projection of DMUo toward the possibility frontier constructed by the reference set and has an input vector $\theta^* \mathbf{x_o} - \mathbf{s}^{-*}$ and an output vector $\mathbf{y_o} + \mathbf{s}^{+*}$.

$$\min \ \theta \quad \text{subject to} \begin{cases} \theta \mathbf{x_o} - \mathbf{X}\lambda \geq 0, \ \mathbf{Y}\lambda \geq \mathbf{y_o} \\ L \leq \mathbf{e}\lambda \leq U, \ \lambda \geq \mathbf{0}, \text{where } \mathbf{e} = (1, \ldots, 1) \end{cases} \tag{1}$$

$$\max_{\lambda, \mathbf{s}^-, \mathbf{s}^+} \ \omega = \mathbf{e}\mathbf{s}^- + \mathbf{e}\mathbf{s}^+ \quad \text{subject to} \begin{cases} \mathbf{s}^- = \theta^* \mathbf{x_o} - \mathbf{X}\lambda, \ \mathbf{s}^+ = \mathbf{Y}\lambda - \mathbf{y_o}, \\ \lambda \geq \mathbf{0}, \ \mathbf{s}^- \geq \mathbf{0}, \ \ \mathbf{s}^+ \geq \mathbf{0} \end{cases} \tag{2}$$

DEA involves two different approaches: an input-oriented approach and an output-oriented approach. The former yields the optimum input mix that is necessary for attaining a certain output level, and the latter provides the optimal output level that is to be obtained from a given input level. As Oda and Otsubo [15] note, the output level of a railway sector has the characteristic of a "derived" demand; we adopt the input-oriented model. Moreover, because previous studies such as Preston [10] state that scale economies remain important in the railway sector, we employ an input-oriented Banker-Charnes-Cooper (BCC-I) model that assumes variable returns to scale by setting $L = U = 1$ [16]. On the other hand, input-oriented Charnes-Cooper-Rhodes (CCR-I) model assumes constant-returns to scale by setting $L = 0$ and $U = \infty$ [17].

The outcome of the BCC-I model reflects the combined outcome of true managerial efficiency as well as the effects of uncontrollable constraints imposed by external conditions.[10] DEA prepares a variation in order to

[10] According to Oum et al. [18], "It is essential that any comparisons of productive efficiency among firms or over time take into account the differences in the factors beyond managerial control" (p.35). Moreover, Oum and Yu [19] stated, "The productive efficiency measured from observable data is also heavily influenced by the market and operating environments to which the railways are subjected. These include factors largely beyond managerial control such as

explicitly deal with such uncontrollable variables. By modifying the model such that the uncontrollable variables are taken into account, an input-oriented, noncontrollable variable model under a variable returns to scale assumption (NCN-IV) model is obtained. In the railway business, it is sometimes stated that transportation density is negatively correlated with business performance (e.g. LRBSG [1]). Thus, we include transportation density variable as a good proxy for environmental variables that determine the potential profitability of the market[11].

The abovementioned efficiencies focus on the technical-physical aspect of production and do not consider cost information. Since we have the unit cost data for input variables, it is possible to construct cost-based efficiency scores by following the methods suggested by Farrell [21] and Debreu [22]. Cost model, a variation of DEA, can accommodate procedures such as a linear programming problem (3), where $\mathbf{c_o}$ is a vector of the unit input cost of DMUo. Based on an optimal solution of (3), $(\mathbf{x}^*, \boldsymbol{\lambda}^*)$, the cost efficiency of DMUo is defined as $\mathbf{c_o x}^* / \mathbf{c_o x_o}$. Here, by setting $L = 0 \,\&\, U = \infty$, we can assume input-oriented constant returns to scale (COST-IC model); when $L = U = 1$, we have a COST-IV model that assumes variable returns to scale.

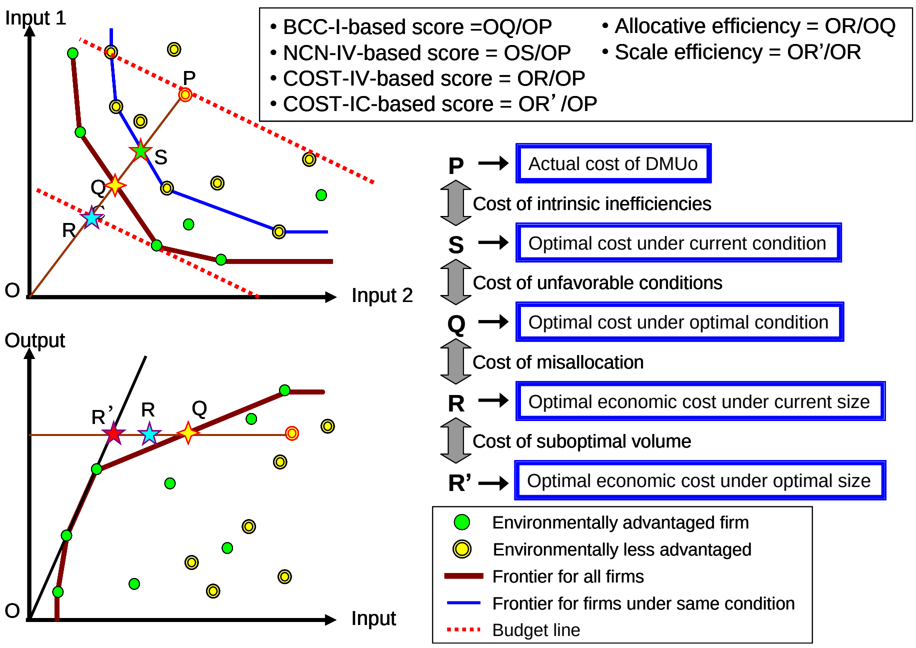
$$\min\ \mathbf{c_o x_o} \ \text{ subject to } \begin{cases} \mathbf{x_o} - \mathbf{X}\lambda \ge 0,\ \mathbf{Y}\lambda \ge \mathbf{y_o} \\ L \le \mathbf{e}\lambda \le U,\ \lambda \ge \mathbf{0} \ \text{where } \mathbf{e} = (1,\ldots,1) \end{cases} \tag{3}$$

When the BCC-based projected DMUo is different from the COST-IV-based projected one, such a difference can be translated into an allocative inefficiency that represents the degree to which the DMUo fails to prepare an optimal input mix ratio. Thus, allocative efficiency scores can be obtained as COST-IV-based scores divided by BCC-I-based scores for each DMU. However, it is important to understand that if a certain DMUo has some extreme input/output values, a certain part of misallocation has already been taken care of as non-radial input slacks,

topography and the climate of the region, the extent of development of other transport modes, traffic density, average load, average distance of haul, the economic development stage of the nation, and so on" (p.121). In addition, by reviewing 211 small rail companies that came into operation from 1970 to 1984, Due [20] presented flexibility in use of labor, general shipper support, and cooperation of major carriers as factors that determine the success of these companies. However, since Due's article addresses railway firms that mainly carry freight, his findings may not be applicable to Japanese railway firms, which are more passenger-oriented.

[11] It is true that transportation density itself is an efficiency index, although it is heavily influenced by surrounding situations that are noncontrollable by individual railway operators.

when estimating the reference point in NCN-IV or BCC-I calculation. Therefore allocation efficiency score can be somewhat biased in this sense. Similarly, scale efficiency is calculated as COST-IC score divided by COST-IV score. We consider the cost-based and BCC-I-based projected DMUo as the overall optimal input mix and the technically optimal input mix, respectively.[12] In addition, NCN-IV-based projected DMUo is representative of the operationally optimal input mix, which shows the target that the DMUo can attain under the surrounding market conditions. Thus, by comparing the corresponding monetary values of each projected input mix, we can evaluate the various inefficiency margins on a comparable scale (Figure 2). For example, an optimal cost corresponding to BCC-I-based projected DMUo, Q, is obtained as $C_o* = \mathbf{p_o}\left(\theta^* \mathbf{x_o} - \mathbf{s}^{-*}\right)$ where $\mathbf{p_o}$ is a vector of unit costs for original DMUo, P. In our framework, the cost of unfavorable or bad environments should be equal to the incentive-compatible subsidy that aims to compensate for regional disparity. Although independently developed, our proposed approach has some aspects that are similar to the approach employed by Tone and Tsutsui [23]. Apart from an apparent difference in the subject of analysis, there exists a major distinction in that our approach explicitly takes an uncontrollable factor into consideration.



Note: The arrangement of this figure is modified for simplicity. For example, projected points are not necessarily linearly-arranged.

Figure 2: DEA-based analytical framework

[12] Although some railway firms enjoy monopoly in their service area, the overall optimal input derived from cost-based model may still have slacks in the economic sense. Thus, cost-based model figures should be interpreted

5. RESULTS AND EVALUATIONS

Table 4 shows the average sample-year results of the DEA evaluation. The estimated monetary value of inefficiency components are presented in Table 5, and its summary is in Table 6, which indicates that, on average, when a railway firm fully rationalizes itself without changing its input mix (except for eliminating non-radial input slacks), the operating cost can become two-thirds. By compensating for unfavorable conditions, the operating cost can be reduced by 9.79%; if a firm can optimize its input mix, it will be further reduced by 9.54%; and by adjusting its size, the cost will be even further reduced by 1.38%. In addition, Table 6 clarifies that our samples have some variations in terms of geography and corporate governance. Firms in the Kyushu area are influenced more heavily by the misallocation of inputs, whereas those in Kinki suffer more through the suboptimal scale, than in the other areas. Private firms are more influenced by an unfavorable environment and the suboptimal scale of operation, whereas semi-public firms suffer more heavily from misallocation. The comparatively smaller impact from the suboptimal scale is similar to a finding of Tone and Tsutsui [23] in the study of electric power firms in Japan and the US; this may imply the appropriateness of market demarcation in utility regulations in the respective industries.

Figure 3 shows the share trend of each inefficiency component value by setting the current cost size as 100%. It shows that poorly managed firms are more influenced by intrinsic inefficiency and less influenced by failure in resource allocation, practical lack of discretion for location change, and suboptimal scale of operation. On the other hand, the Kendall's tau-b statistics of the bivariate rank correlation between the efficiency scores obtained from BCC and NCN models turns out to be 0.757, which is quite high. This implies that the impact of lack of discretion for location change is large for better managed firms, but not large enough to reverse the efficiency ranking.

The optimal amount of subsidy as compensation for regional disparity, or for the practical lack of discretion for location change, must be just equal to the monetary value of the unfavorable environment in Column 6 of Table 5. We can use these figures to judge the appropriateness of the subsidy scheme that is currently being applied. National and municipal governments continue to spend large sums of money on the railway system in Japan; it is possible to evaluate the appropriateness of such public intervention by comparing actual subsidies with our estimated optimal level. For example, Miki railway lost 64 million yen in 2004, which was fully reimbursed by the municipal government. Based on our model, the optimal subsidy as compensation for only regional disparities is estimated at 1.4 million yen, which indicates that the subsidy is extremely high for securing an efficient operation and may be giving an incorrect message to a railway manager, unless the size of the fixed cost can fill the gap.

---

cautiously.

Table 4: Efficiency scores of the sample firms

Area	Control	Company Name	Technical Efficiency		Overall Efficiency		Allocative	Scale
			NCN-based	BCC-based	COST-IV-based	COST-IC-based	Efficiency	Efficiency
Tokyo metropolitan area	private	Choshi	0.4475	0.3219	0.2825	0.2669	0.8810	0.9551
		Enoshima	0.4577	0.2864	0.2022	0.2019	0.7158	0.9986
		Fujikyu	0.3009	0.2547	0.2340	0.2332	0.9186	0.9966
		Ibaraki	0.5279	0.4238	0.3050	0.3038	0.7253	0.9958
		Jomo	0.6002	0.5560	0.2558	0.2550	0.4603	0.9969
		Joshin	0.6081	0.5733	0.2938	0.2934	0.5129	0.9988
		Kanto	0.5607	0.5324	0.2870	0.2869	0.5426	0.9996
		Kashima	0.3540	0.3384	0.2506	0.2471	0.7417	0.9868
		Keihin	0.9086	0.8998	0.8249	0.8249	0.9176	1.0000
		Keio	0.9985	0.9817	0.9729	0.9711	0.9909	0.9982
		Keisei	0.6149	0.6106	0.5780	0.5779	0.9473	0.9999
		Kominato	0.7963	0.7498	0.2858	0.2853	0.3824	0.9982
		Odakyu	0.9993	0.9990	0.9938	0.9573	0.9948	0.9632
		Sagami	1.0000	0.9151	0.7830	0.7830	0.8557	1.0000
		Seibu	0.9948	0.8799	0.8381	0.8246	0.9541	0.9838
		Shin-Keisei	0.9730	0.8263	0.6503	0.6503	0.7881	0.9999
		Soubu-Nagareyama	0.9881	0.5709	0.2762	0.2757	0.4842	0.9981
		Tokyu	0.9631	0.9356	0.7621	0.7414	0.8199	0.9726
	semi-public	Hokusou	0.4711	0.4231	0.2990	0.2989	0.7068	0.9995
		Isumi	0.6893	0.6518	0.3380	0.3365	0.5269	0.9957
		Moka	0.9881	0.9809	0.4616	0.4609	0.4712	0.9984
		Tokyo rinkai	0.2478	0.1494	0.0741	0.0738	0.5388	0.9967
		Toyo	0.6401	0.4680	0.2117	0.2117	0.4529	0.9998
		Watarase	0.7782	0.6334	0.2824	0.2821	0.4447	0.9989
		Yagan	0.4163	0.4137	0.2153	0.2129	0.5206	0.9888
Kinki area	private	Eizan	0.4056	0.2961	0.2122	0.2118	0.7218	0.9985
		Hankyu	0.9713	0.9373	0.8844	0.8708	0.9451	0.9848
		Hanshin	0.6014	0.5491	0.5406	0.5406	0.9847	1.0000
		Hokushin	0.6942	0.3988	0.1748	0.1748	0.4402	0.9999
		Keihan	0.8722	0.8589	0.6934	0.6934	0.8076	1.0000
		Kintetsu	1.0000	0.9839	0.9568	0.5520	0.9723	0.5784
		Kisyu	1.0000	0.9993	0.9859	0.9077	0.9865	0.9207
		Kita-Osaka	0.9917	0.5353	0.5300	0.5298	0.9901	0.9996
		Kobe	0.5322	0.5176	0.3503	0.3503	0.6767	0.9999
		Mizuma	0.7430	0.3488	0.2934	0.2920	0.8413	0.9953
		Nankai	0.6024	0.5522	0.4927	0.4927	0.8935	1.0000
		Nose	0.6869	0.4955	0.4099	0.4096	0.8328	0.9993
		Omi	0.2534	0.2452	0.2145	0.2142	0.8771	0.9983
		San-yo	0.5159	0.4934	0.4346	0.4345	0.8810	0.9999
	semi-public	Hojo	0.9589	0.9437	0.5602	0.5580	0.5928	0.9963
		Kita-Kinki-Tango	0.3076	0.2634	0.1567	0.1567	0.5957	0.9997
		Miki	0.4621	0.4462	0.4302	0.4277	0.9643	0.9943
		Osaka-Toshi	0.6962	0.5204	0.5164	0.5163	0.9922	0.9998
		Shigaraki	0.9359	0.8246	0.4275	0.4251	0.5171	0.9948
Kyushu area	private	Chikuhou	0.5402	0.3989	0.2778	0.2774	0.6965	0.9985
		Kumamoto	0.6380	0.5506	0.4490	0.3411	0.7839	0.8876
		Nishi-nihon	0.6591	0.6581	0.6547	0.6547	0.9947	1.0000
		Shimabara	0.4385	0.4338	0.2174	0.2172	0.5032	0.9993
	semi-public	Amagi	0.7778	0.6552	0.4278	0.4257	0.6531	0.9951
		Kumagawa	0.9910	0.9901	0.5102	0.5097	0.5154	0.9990
		Matsuura	0.9917	0.8522	0.3502	0.3496	0.4114	0.9983
		Minami-Aso	0.9562	0.9461	0.5666	0.5645	0.5997	0.9963
		Takachiho	0.9144	0.6904	0.3618	0.3604	0.5253	0.9963

Table 5: Value of inefficiencies

Area	Control	Company Name	Actual cost	Monetary value of inefficiency components: Intrinsic ineffi.	Bad envrnmt.	Misallocation	Subopt. Scale	Optimal cost
Tokyo metropolitan area	private	Choshi	186,170	102,989	23,889	6,632	3,061	49,600
		Enoshima	1,924,135	1,095,384	432,719	7,131	529	388,371
		Fujikyu	1,193,239	838,188	56,930	19,650	920	277,550
		Ibaraki	268,245	144,202	37,893	4,287	339	81,525
		Jomo	677,227	300,184	44,340	159,791	539	172,373
		Joshin	875,343	424,528	71,048	122,168	314	257,284
		Kanto	2,729,481	1,815,368	113,333	17,376	282	783,121
		Kashima	303,295	209,201	10,020	8,486	1,019	74,568
		Keihin	55,122,335	7,734,458	858,390	1,023,814	1,046	45,504,626
		Keio	57,085,270	128,668	907,137	502,604	100,242	55,446,619
		Keisei	42,258,472	17,309,756	367,641	161,610	1,395	24,418,070
		Kominato	700,010	430,930	49,669	18,849	390	200,171
		Odakyu	80,939,964	97,903	18,116	390,437	2,979,032	77,454,476
		Sagami	25,541,724	0	5,236,582	304,712	517	19,999,913
		Seibu	78,090,130	544,926	11,299,905	816,704	1,076,779	64,351,817
		Shin-Keisei	9,388,277	435,368	2,303,535	543,260	620	6,105,493
		Soubu-Nagareyama	565,026	9,272	369,253	29,850	305	156,347
		Tokyu	98,061,211	6,991,102	2,367,542	14,347,721	2,074,034	72,280,812
	semi-public	Hokusou	7,504,683	4,792,716	276,333	191,619	1,177	2,242,838
		Isumi	266,989	95,617	2,534	78,626	380	89,832
		Moka	463,163	6,978	2,533	239,669	354	213,629
		Tokyo rinkai	5,887,355	5,098,233	280,913	20,164	1,164	486,881
		Toyo	9,968,322	7,096,218	735,076	35,508	424	2,101,096
		Watarase	417,136	115,302	53,350	130,968	126	117,390
		Yagan	559,847	344,543	-13,738	108,305	1,325	119,412
Kinki area	private	Eizan	1,080,565	657,327	188,477	6,133	348	228,280
		Hankyu	80,784,210	2,312,609	2,733,706	4,231,871	1,103,882	70,402,143
		Hanshin	23,038,867	9,542,318	992,292	57,458	331	12,446,468
		Hokushin	1,694,157	1,161,448	156,538	81,789	28	294,354
		Keihan	45,290,149	12,593,795	1,258,720	22,577	633	31,414,423
		Kintetsu	148,845,719	0	2,742,328	3,327,550	60,651,114	82,124,727
		Kisyu	32,504	0	319	108	2,917	29,159
		Kita-Osaka	4,300,033	74,873	1,927,793	17,295	873	2,279,199
		Kobe	9,812,599	6,102,416	247,728	4,973	398	3,457,083
		Mizuma	306,550	87,581	112,515	16,759	428	89,267
		Nankai	51,987,877	22,359,474	3,934,405	7,666	391	25,685,942
		Nose	3,058,290	1,198,856	542,846	62,474	832	1,253,282
		Omi	1,014,707	770,744	21,549	4,688	366	217,360
		San-yo	14,097,149	7,336,887	525,939	127,330	349	6,106,643
	semi-public	Hojo	94,315	6,124	177	35,430	195	52,388
		Kita-Kinki-Tango	2,039,468	1,508,928	52,673	158,209	110	319,548
		Miki	92,049	50,158	1,397	963	225	39,305
		Osaka-Toshi	7,552,471	2,339,536	1,291,847	31,623	662	3,888,802
		Shigaraki	258,213	82,209	16,076	68,090	473	91,365
Kyushu area	private	Chikuhou	1,424,897	670,779	196,336	163,704	594	393,483
		Kumamoto	247,655	90,728	24,213	23,473	24,872	84,370
		Nishi-nihon	20,441,632	6,964,183	19,635	72,907	553	13,384,355
		Shimabara	953,010	734,691	6,153	4,156	148	207,862
	semi-public	Amagi	228,302	51,608	31,951	47,141	481	97,122
		Kumagawa	220,212	1,925	212	105,996	115	111,965
		Matsuura	859,911	18,380	271,168	269,086	514	300,763
		Minami-Aso	103,817	5,487	742	38,910	220	58,459
		Takachiho	256,775	20,772	58,744	84,072	360	92,827

Note : All figures are in thousands and sample year average.

Table 6: Impact of various inefficiencies on operating cost

	Actual Cost	−	Intrinsic inefficiency	−	Unfavorable environment	−	Misallocation	−	Suboptimal Scale	=	Optimal Cost
Overall average	100.00	−	35.46	−	9.79	−	9.54	−	1.38	=	43.83
Tokyo metropolitan area	100.00	−	37.75	−	9.70	−	8.70	−	0.41	=	43.44
Kinki area	100.00	−	36.95	−	9.62	−	5.05	−	2.74	=	45.64
Kyushu area	100.00	−	25.98	−	10.39	−	21.34	−	1.20	=	41.09
private	100.00	−	35.96	−	10.95	−	3.53	−	1.98	=	47.58
semi-public	100.00	−	34.41	−	7.32	−	22.27	−	0.11	=	35.89

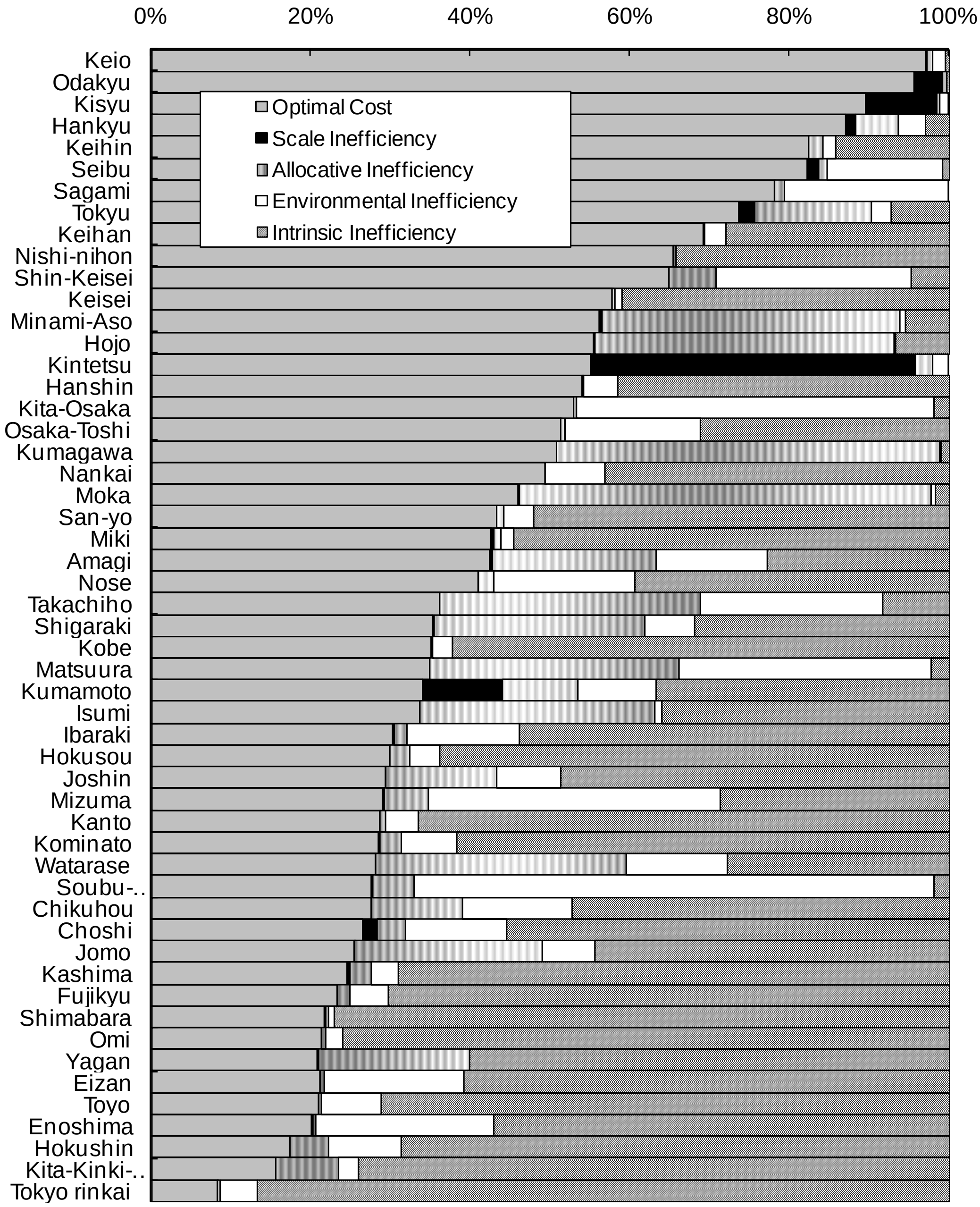


Figure 3: Causes of inefficient operations

Liu and Tone [24] proposed a different approach to single out the impact of environmental factors when measuring DMU's efficiency. Adopting an output-oriented framework, they employed a weighted slack-based measure (SBM) model[13] and measured output-slacks, which include radial and non-radial ones. They then employed stochastic frontier analysis (SFA) in order to attribute such slacks either to management incompetence,

[13] The SBM model was introduced by Tone [25] and weight SBM model, a SBM model that allocate pre-determined weights on input and output variables, was explained in Cooper et al. [26, p.105].

disadvantageous environments, or data noises; adjusted outputs by filtering out an environmental impact as well as a data noise impact; and finally adopted such adjusted outputs for DEA procedure.

In order to compare their methodology with ours, firstly, we ran an input-oriented weighted SBM model, which assumes variable returns to scale, on our DMU set and calculated input slacks (s_{rjt}^{-*}) for input r of company j at year t. As for the weight of the model, we employed equal weight among the input variables since we could not find any better alternatives. Then, we practiced SFA estimations, employing SBM-based slack ratio to each input variable as an explained variable, in order to single out an environmental contribution from these slacks and constructed environmentally-optimized input variables. Transportation density was again used as a primary environmental factor. In order to generate variance regressors, we estimated a fixed effects linear model where "Operating Margin Ratio (OMR)" and "Depreciation divided by Operating Income (DOI)" are explained variables and transportation density (TD) as an explaining variable (Equation 4). Then, we singled out group-wise, or company-specific, fixed effects (α_j) and error terms (ε_{jt}); these fixed effects, FIXED1 and FIXED2, are used for variance regressors in SFA's symmetric components; whereas the error terms, RES1 and RES2, are for variance regressors in SFA's one-sided components (Equation 5). Table 8 shows the results of SFA estimation.

$$OMR_{jt} \; or \; DOI_{jt} = \alpha_j + \beta TD_{jt} + \varepsilon_{jt} \tag{4}$$

Table 7: Results of fixed effect model estimation

Explained variable	Operating Margin Ratio			Depreciation/Operating Income		
N		305			305	
F[52, 252]		88.11	***		102.64	***
Log likelihood		397.52			630.83	
Restricted(b=0)		-52.96			158.21	
Chi-sq [52]		900.96	***		945.26	***
LogAmemiya Prd. Crt.		-5.09			-6.62	
Akaike Info. Criter.		-5.10			-6.63	
Variable	Coefficient	Standard Error		Coefficient	Standard Error	
Transportation Density	6.84E-06	4.01E-06	**	-3.90E-06	1.87E-06	***

Note: *** indicates p<0.01.

$$
\begin{cases}
\dfrac{s_{rjt}^{-*}}{original\ Y_{rjt}} = \beta_{r0} + \beta_{r1} TD + v_{rjt} + u_{rjt} \\
v_{rjt} \sim N\left[0, \sigma_{vrjt}^2\right] \\
u_{rjt} = \left|U_{rjt}\right| \ and\ U_{rjt} \sim N\left[0, \sigma_{urjt}^2\right] \\
\sigma_{vrjt}^2 = \sigma_v^2 \exp\left(\delta_{r0} + \delta_{r1}\, FIXED1 + \delta_{r2}\, FIXED2 + \delta_{r3}\, D\_AREA1 + \delta_{r4}\, D\_AREA2\right) \\
\sigma_{urjt}^2 = \sigma_u^2 \exp\left(\gamma_{r0} + \gamma_{r1}\, RES1 + \gamma_{r2}\, RES2 + \gamma_{r3}\, D\_PUBLIC\right)
\end{cases}
\tag{5}
$$

Table 8: Results of SFA estimation (variable returns to scale)

Dependent variable		SBM-based slack ratio of operating expenditure			SBM-based slack ratio of related fixed asset			SBM-based slack ratio of staff		
Weighting variable		None			None			None		
Number of observations		305			305			305		
Iterations completed		20			55			28		
Log likelihood function		34.1915			-34.8366			48.9094		
Number of parameters		11			11			11		
Info. Criterion: AIC		-0.1521			0.3006			-0.2486		
Finite Sample: AIC		-0.1491			0.3035			-0.2456		
Info. Criterion: BIC		-0.0179			0.4347			-0.1144		
Info. Criterion:HQIC		-0.0984			0.3542			-0.1949		
Variances	s^2(v)	0.0493			0.0739			0.0853		
	s^2 (u)	0.0414			0.0037			0.0101		
	s(v)	0.2220			0.2718			0.2920		
	s(u)	0.2035			0.0605			0.1006		
Sigma = Sqr[(s^2(u)+s^2(v)]		0.3012			0.2784			0.3089		
Variable		Coefficient	Standard Error		Coefficient	Standard Error		Coefficient	Standard Error	
---------+Primary Index Equation for Model										
Constant		0.3926	0.0285	***	0.5090	0.0406	***	0.5880	0.0322	***
Transportation Density		-5.40E-06	4.77E-07	***	-3.50E-06	9.68E-07	***	-7.72E-06	3.58E-07	***
---------+Parameters in variance of v (symmetric)										
Constant		-3.0683	0.2443	***	-2.8287	0.2439	***	-2.4766	0.1961	***
FIXED1		-2.6051	0.7337	***	0.1206	0.4653		-2.8744	0.4294	***
FIXED2		-6.3455	1.3890	***	0.6759	0.7032		-7.6075	1.1387	***
D_AREA1		0.8807	0.4009	***	0.3517	0.3070		1.1914	0.3997	***
D_AREA2		1.1500	0.3590	***	0.0125	0.2823		0.9682	0.2909	***
---------+Parameters in variance of u (one sided)										
Constant		-3.4708	0.3944	***	-7.2261	4.1104	*	-5.2310	1.1208	***
RES1		-1.3501	1.1798		24.1737	27.4377		-2.4561	2.4370	
RES2		-1.4829	2.1938		66.8660	80.2378		-0.2943	2.0689	
D_PUBLIC		0.6873	0.3504	**	-3.6319	7.6441		1.2845	0.9002	

Note1: D_AREA1, D_AREA2, and D_PUBLIC equal 1 if and only if the sample is in Tokyo metropolitan area, in Kinki area, and operated by semipublicly, respectively; otherwise 0.
Note2: *, **, and *** indicate p<0.1, p<0.05, and p<0.01, respectively.

Then, in the following Equation 6, we calculated environmentally optimized input variables and ran the weighted SBM model to determine the Liu-Tone based efficiency scores.

$$
optimized\ Y_{rjt} = original\ Y_{rjt}\left(1 - \left(\hat{\beta}_{r0} + \hat{\beta}_{r1} TD + \hat{u}_{rjt}\right)\right) \tag{6}
$$

The authors also tried a constant-returns-to-cost-based SBM model and repeated the similar procedure as just explained. Table 9 indicates the SFA results based on constant returns to cost assumption.

Table 9: Results of SFA estimation (constant returns to scale)

Dependent variable	SBM-based slack ratio of operating expenditure			SBM-based slack ratio of related fixed asset			SBM-based slack ratio of staff		
Weighting variable	None			None			None		
Number of observations	305			305			305		
Iterations completed	24			22			64		
Log likelihood function	47.3849			-14.0770			72.8719		
Number of parameters	11			11			11		
Info. Criterion: AIC	-0.2386			0.1644			-0.4057		
Finite Sample: AIC	-0.2356			0.1674			-0.4028		
Info. Criterion: BIC	-0.1044			0.2986			-0.2715		
Info. Criterion:HQIC	-0.1849			0.2181			-0.3521		
Variances $s^2(v)$	0.0426			0.0672			0.0676		
s^2 (u)	0.0465			0.0483			0.0022		
s(v)	0.2065			0.2593			0.2600		
s(u)	0.2157			0.2198			0.0472		
Sigma = Sqr[(s^2(u)+s^2(v)]	0.2986			0.3399			0.2643		
Variable	Coefficient	Standard Error		Coefficient	Standard Error		Coefficient	Standard Error	
---------+Primary Index Equation for Model									
Constant	0.4004	0.0238	***	0.5276	0.0415	***	0.6428	0.0752	***
Transportation Density	-5.62E-06	4.55E-07	***	-5.24E-06	5.40E-07	***	-8.34E-06	5.86E-07	***
---------+Parameters in variance of v (symmetric)									
Constant	-3.1477	0.2585	***	-2.4327	0.2644	***	-3.1637	0.1535	***
FIXED1	-3.6118	1.1357	***	-3.3267	0.7828	***	-4.0754	0.5669	***
FIXED2	-6.6504	1.3657	***	-4.5506	1.2111	***	-2.7127	0.5223	***
D_AREA1	0.8402	0.4579	*	0.2568	0.3279		1.2691	0.3616	***
D_AREA2	0.5442	0.5097		-0.2696	0.3942		-0.2639	0.2469	
---------+Parameters in variance of u (one sided)									
Constant	-3.2547	0.3148	***	-3.4160	0.4111	***	-5.7045	3.2542	
RES1	-2.0089	1.0543	*	0.5170	0.8727		-0.5630	5.7701	
RES2	-0.9644	2.2801		0.5685	2.8183		0.0190	17.5396	
D_PUBLIC	0.4641	0.3150		0.8829	0.3142	***	-56.3269	5.64E+12	

Note1: D_AREA1, D_AREA2, and D_PUBLIC equal 1 if and only if the sample is in Tokyo metropolitan area, in Kinki area, and operated by semipublicly, respectively; otherwise 0.
Note2: *, **, and *** indicate p<0.1, p<0.05, and p<0.01, respectively.

By these procedure, we can find the Liu-Tone-based reference points that are equivalent to S, Q, R, and R' of Figure 2; and can generate the table of inefficiency costs (Table 10) which can be comparable to Table 6. This result indicates that, although the estimated optimal costs of each methodology looks similar (the correlation coefficient is 0.829), Liu-Tone methods allocates more inefficiency on environmental factors than ours. Which method is more close to the reality will be the research topic of further analysis.

Table 10: Results of Liu-Tone style inefficiency impacts

	Actual Cost	−	Intrinsic Inefficiency and Misallocation	−	Unfavorable environment	−	Suboptimal Scale	=	Optimal Cost
Overall average	100.00	−	5.53	−	36.81	−	2.40	=	55.27
Tokyo metropolitan area	100.00	−	3.74	−	28.18	−	2.96	=	65.12
Kink area	100.00	−	6.53	−	36.03	−	3.46	=	53.99
Kyushu area	100.00	−	5.40	−	40.70	−	1.34	=	52.56
private	100.00	−	5.65	−	40.66	−	2.19	=	51.49
semi-public	100.00	−	5.27	−	29.02	−	2.82	=	62.88

Finally, through the application of DEA models, we can derive a set of reference and projected DMUs which can be categorized as the most productive scale size or MPSS [27]. The location of MPSS is where DMUos that are judged efficient both from BCC-I model and from CCR-I model exist, or where BCC-I model judges a range of constant returns to scale. On the other hand, following Cooper et al [26, chap.12), degree of scale economies (ρ), or more accurately its upper and lower bound, can be measured by the following linear program. The returns to scale is said to be increasing, constant and decreasing if $\rho > 1$, $\rho = 1$ and $\rho < 1$ respectively.

$$\overline{\rho} = 1 + \overline{\omega} \ \textit{and} \ \underline{\rho} = 1 + \underline{\omega} \tag{7}$$

$$\text{where} \quad \overline{\omega}(\underline{\omega}) = \max(\min)\omega \quad \text{subject to} \quad \begin{cases} \mathbf{vx_0} = 1 \\ \mathbf{vX} - \mathbf{uY} + \mathbf{e}\omega \geq 0 \\ \mathbf{vx_0} - \mathbf{uy_0} + \omega = 0 \\ \mathbf{v} \geq \mathbf{0}, \mathbf{u} \geq \mathbf{0}, \omega : \text{free in sign} \end{cases} \tag{8}$$

Table 11 shows the ranges of ρ and input variables of increasing, constant, and decreasing returns to scale DMUs; where MPSS corresponds to the middle. Here, for simplicity reason, we use DMUs from 2003's sample only. It shows that DEA-based judgment of the returns to scale generally corresponds to estimated range of ρ. Among the 14 "BCC-I efficient" DMUs, Hankyu, Hojo, Keio, Kisyu, Kumagawa, Minami-Aso, Moka, and Odakyu,are within the range of MPSS; whereas Kashima, Kintetsu, Matsuura, Seibu, Shin-Keisei, and Tokyu are beyond the MPSS range, or within the range of decreasing returns to scale.

Table 11: Returns to scale and degree of scale economies

	Returns to Scale Judgment by BCC-I model								
	Increasing			Constant			Decreasing		
$\overline{\rho}$ (Upper bound of ρ)	1.000	~	1.000	1.000	~	2.105E+16	1.085	~	3.602E+16
$\underline{\rho}$ (Lower bound of ρ)	0.727	~	0.993	0.000	~	1.000	1.005	~	49.176
Fixed Asset (yen)	37,638.2	~	52,552,106.5	22,442.0	~	452,892,668.0	41,309.8	~	741,718,013.0
Employee (person)	9.7	~	506.9	5.0	~	3,320.0	17.6	~	5,669.0
Operating expenditure (yen)	36,769.5	~	4,885,858.4	9,563.0	~	41,821,334.0	50,414.0	~	59,153,395.0

6. CONCLUSION AND REMAINING ISSUES

In this article, we proposed a method to measure inefficiency in monetary terms and to differentiate their source by using a DEA framework, and applied the method to 53 railway firms in Japan. We also showed that our proposed DEA approach can be used to generate the optimal size of subsidy as compensation for regional disparities that should be equal to the value of an unfavorable environment for securing incentive compatibility. These estimates, when combined with the size of the fixed cost of railway operation under the diminishing average cost structure, are the target figures that national or municipal governments should subsidize without hampering the efficient operation of railway firms. It is true that, as DEA scores are obtained through peer comparisons, firms may be able to affect the DEA scores by collusion, which may deteriorate the effectiveness of our proposed subsidy. However, according to Armstrong et al. [28], such collusion becomes difficult to arrange when there are too many firms involved. We believe that such collusion is less likely to occur given the large number of Japanese railway firms.

There still remain several drawbacks in our analysis. The most concerning drawback is the robustness of the DEA approach. Since the efficiency index is very vulnerable to model configuration, we may need to employ an alternative configuration in order to verify the robustness of our findings. It may also be important to identify other uncontrollable factors and incorporate them in our analysis. Second the estimated unit cost or optimized operating costs are not based on economic costs. In our analysis, we calculated such figures using the financial statements of the railway firms involved in our study because we could not find any other alternative. Although such accounting figures are convenient, they are not perfectly appropriate for economic analysis because financial statements are based on the historical cost, whereas economic costs need to reflect the opportunity cost. Finally, since the possible disparity between DEA-based and economic-based optimality in the often monopolistic railway industry requires additional attention, it should be included in our future research agenda.

We hope that our proposal will help corporate managers and related policymakers determine proper efficiency-improving strategies and that our efforts here represent a meaningful contribution to the field of DEA application.

Acknowledgement

This article is based on the presentations made by the authors at the 9th PRSCO Summer Institute in Kuala Lumpur, Malaysia, in July 2006, as well as at the DEA symposium in Osaka, Japan, in February 2007. The authors would like to thank Dr. Kaoru Tone (GRIPS), Prof. Toru Ueda (Seikei University), and Prof. Toru Nakai (Kyushu University) for their useful comments. This study is partially supported by a Grant-in-Aid for Scientific Research ([A], No.18201030) from the Japan Society for the Promotion of Science, by the International Exchange Fund of Faculty of Economics, Kyushu University, and by the Tezukayama Research Fund.

REFERENCES

[1] Local Railway Business Study Group (LRBSG). 2003. *Revitalization plan for local railway sector: self-help efforts and government intervention* [Chihou tetsudou fukkatsu no tame no shinario: tetsudou jigyousha no jijodoryoku to kuni chihou no tekisetsuna kan-yo] [online document]. http://www.jterc.or.jp/ chiho_tetudo /chiho_hokoku.pdf [retrieved on May 13, 2006].

[2] Asahi Shimbun Publishing Co. (ed). *Minryoku 1989-2005 CD-ROM for Windows & Macintosh*. Tokyo, Japan: Asahi Shimbun Publishing Co; 2005.

[3] Mitomo, Hitoshi and Toshiya Jitsuzumi. Impact of telecommuting on mass transit congestion: the Tokyo case. *Telecommunications Policy* 1999;23(10/11):741-51.

[4] Mizutani, Fumitoshi. Privately owned railways' cost function, organization size and ownership. *Journal of Regulatory Economics* 2004;25(3):297-322.

[5] Mizutani, Fumitoshi. *Japanese urban railways: a private-public comparison*. Aldershot, UK: Avebury; 1994.

[6] Institution for Transport Policy Studies (ITPS). *Transportation Policy and Regional Development* [Kotsu Seisaku to Chiiki Shinko]. Tokyo, Japan: ITPS; 2004a.

[7] ITPS. *Statistics of Railways 2004* [Suuji de Miru Tetsudo 2004]. Tokyo, Japan: ITPS; 2004b.

[8] Nakamura, Akihiro and Toshiya Jitsuzumi. A DEA-based pricing method for railtrack usage: taking the value of local services into account [Tetsudou jigyo no koukyousei wo kouryosita senro siyouryou no kettei houhou ni kansuru kentou –DEA ni yoru senro fusetsu kanri no yardstick sihyou no keisoku-]. *Annual Report on Transportation Economics* 2004;47:59-68.

[9] Hensher, David A., Rhonda Daniels, and Ian DeMellow. A comparative assessment of the productivity of Australia's public rail systems 1971/72-1991/92. *The Journal of Productivity Analysis* 1995;6:201-23.

[10] Preston, John. The economics of British Rail privatization: an assessment. *Transport Reviews* 1996;16(1):1-21.

[11] Nakajima, Takanobu and Yoshitaka Fukui. Total Factor productivity of Japanese railway enterprises [Nihon no tetsudou jigyou no zen youso seisannsei]. *Transportation and Economy* 1996;56(1):32-40.

[12] Railway Bureau, Ministry of Land, Infrastructure and Transport (MLIT). (ed). *Annual statistics of railway [Tetsudou toukei nenpou]*. Tokyo, Japan: Government Data Research Center of Japan; 2000-2005.

[13] Cooper, William W., Lawrence M. Seiford, and Kaoru Tone. *Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software*. Boston, Massachusetts: Kluwer Academic Publishers; 1999.

[14] Banker, Rajiv D., Abraham Charnes, and William W. Cooper. Some models for estimating technical and scale

inefficiencies in data envelopment analysis. *Management Science* 1984;30(9):1078-92.

[15] Oda, Kyoji and Yoshiaki Otsubo. The productivity of all the elements of railway enterprise after privatisation of the Japanese national railways. *Transportation and Economy* 2000;60(2):52-60.

[16] Banker, Rajiv D., Abraham Charnes, William W. Cooper, and Ajay Maindiratta. A comparison of DEA and translog estimates of production frontiers using simulated observations from a known technology. In *Applications Modern Production Theory: Efficiency and Productivity*, edited by Ali Dogramaci and Rolf Färe, 33-55. Boston, Massachusetts: Kluwer Academic Publishers 1988.

[17] Charnes, A., Cooper, W. W., and Rhodes, E. Measuring the efficiency of decision making units. *European Journal of Operational Research*, 1978;2(6): 429-444.

[18] Oum, Tae H., William G. Waters II, and Chunyan Yu. A survey of productivity and efficiency measurement in rail transport. *Journal of Transport Economics and Policy* 1999;33(Part.1):9-42.

[19] Oum, Tae H. and Chunyan Yu. Economic efficiency of railways and implications for public policy: a comparative study of the OECD countries' railways. *Journal of Transport Economics and Policy* 1994;28(2):121-38.

[20] Due, John F. Abandonment of rail lines and the smaller railroad alternative. *Logistics and Transportation Review* 1987;23(1):109-34.

[21] Farrell, Micheal J. The measurement of productive efficiency. *Journal of the Royal Statistical Society* 1957;120(3):253-90.

[22] Debreu, Gerard. The coefficient of resource utilization. *Econometrica* 1951;19(3):273-92.

[23] Tone, Kaoru and Miki Tsutsui. Decomposition of cost efficiency and its application to Japanese-US electric utility comparisons. *Socio-Economic Planning Sciences* 2007;41(2):91-106.

[24] Liu, Junming and Kaoru Tone. A multistage method to measure efficiency and its application to Japanese banking industry. *Socio-Economic Planning Sciences* 2008;42(2):75-91.

[25] Tone, Kaoru. A slacks based-measure of efficiency in data development analysis. *European Journal of Operational Research* 2001;130(3): 498-509.

[26] Cooper, William W., Lawrence M. Seiford, and Kaoru Tone. *Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software, Second edition*. Boston, Massachusetts: Kluwer Academic Publishers; 2007.

[27] Banker, Rajiv D. Estimating most productive scale size using data envelopment analysis. *European Journal of*

Operational Research 1984;17(1):35-44.

[28] Armstrong Mark, Simon Cowan, and John Vickers. *Regulatory Reform: Economic Analysis and British Experience*. Cambridge, MA: MIT Press; 1994.