

Cost Efficiency and Optimal Scale of Electricity Distribution Firms in Taiwan: An Application of Metafrontier Analysis

Yi-Ju Huang
Tamkang University

Ku-Hsieh Chen
Fo Gang University

Chih-Hai Yang*
Department of Economics
National Central University

Abstract

This paper analyzes the cost efficiency and optimal scale of the electricity distribution industry in Taiwan. Due to the substantial difference in network density, firms may differ widely in production technology. We employ the stochastic metafrontier approach to estimate the cost efficiency of 24 distribution units during the period of 1997 and 2002. Empirical results find that the average cost efficiency is overestimated using the traditional stochastic frontier model, especially for low density regions. The average cost efficiency of high density group is significantly higher than that of low density group benefited from the network economies. Both short-term and long-term optimal scale of electricity distribution firms is also calculated in this study, lending policy implications for the deregulation of the electricity distribution industry.

Key words: Efficiency, Electricity distribution, Metafrontier, Optimal scale

JEL Classification: C2, O47, O53

* Corresponding Author: Department of Economics, National Central University, 300, Jhongda Road, Jhongli 320, Taiwan. Tel.: +886-3-4227151 ext 66318. E-mail: chyang@mgt.ncu.edu.tw.

1. Introduction

The electricity sector has been witnessed considerable deregulation and liberalization in many countries over the past couple decades, such as Australia, Norway, New Zealand, Sweden, Switzerland, and the U.K. After the introduction of competition into the generation sector, regulatory reform and incentive regulation have also been introduced into the electricity distribution sector. With the planned introduction of the new “Amended Electricity Act” that has been ruled upon by the Executive Yuan, but still under legislative discussion, Taiwan’s government plans to liberalize the distribution of electricity by privatizing existing state-owned distribution utilities and permitting new entrants, aiming to improve the sector’s efficiency. This policy is particularly important for Taiwan which lacks abundant energy resources.

To ensure the success of policy execution, there are two essential questions should be examined carefully. The first one is how many segmented markets should be classified in Taiwan? In other words, what is the optimal scale of an electricity firm? Utilizing the historical cost and output information of existing distribution firms coupled with predictions on electricity usage, we can assess the optimal size of the service territory by using an average cost distance function approach (e.g. Growitsch *et al.*, 2008) or data development analysis approach (e.g. Erbetta and Rappuoli, 2008) from the economical perspective.¹

Most important and hotly debated is the second issue, that is, the efficiency estimation of distribution companies. Even though the electricity distribution industry has been liberalized, the electricity distribution utilities will have strong market power within their service territories as usual, indicating a rate regulation by the authorities is necessary. There are several regulatory practices in the electricity market, such as yardstick competition and incentive regulation.² Basically, we can implement those models in

¹ There are other important factors influencing the decision on the optimal number of segmented markets, such as the composition of consumers and topographical features.

² Jamasb and Pollitt (2001) provide a comprehensive survey of different regulation practices in electricity

practice based on *benchmarking* - that is, measuring a firm's efficiency against a reference firm's performance. According to the estimated X-inefficiency which is the deviation from the optimal point on the cost (production) frontier to the real cost (production) level, the regulatory commission can reward or punish firms from a benchmarking application. Therefore, the reliability of the efficiency score is particularly crucial in regulatory practices.

To measure the inefficiency scores of electricity distribution utilities, existing studies have employed two primary approaches. The first category is a parametric technique that requires a particular functional form to be specified for the cost or production frontier, such as the stochastic frontier approach (SFA).³ The second approach is the non-parametric data envelopment analysis (DEA) which places less structure on the shape of the efficiency frontier. Both parametric and non-parametric techniques have their own merit (Coelli *et al.*, 2005), and the selection of a suitable estimation method is controversial and influences the regulatory policy derived from its analysis. For the non-parametric approach, Bagdadioglu *et al.* (1996) utilize DEA to analyze the performance of Turkey's public and private electricity distribution utilities. The same methodology is applied to estimate the efficiency of distribution utilities around the world, such as Sweden (Hjalmarsson and Veiderpass, 1992), Australia, Sweden, and New Zealand (Zhang and Bartels, 1998), Philippines (Pacudan and Guzman, 2002), U.K. (Giannakis *et al.*, 2005), Taiwan (Chen, 2002), and Scandinavian Electricity Distribution (Agrell *et al.*, 2005). On the other hand, the SFA is also widely adopted in existing studies, such as Burn and Weyman-Jonse (1996) for the U.K., Hattori (2002) for the U.S. and Japan, Jamasb and Pollitt (2003) and Growitsch *et al.* (2008) for European countries, Farsi and Filippini (2004) for Switzerland, and Filippini *et al.* (2004) for Slovenia.

Firms in different regions face different production opportunities that force them to

markets across countries.

³ There are two alternative approaches to parametric techniques, including the thick frontier approach (TFA) and the distribution-free approach (DFA).

make choices between different sets of feasible input-output combinations. This difference can be attributed to the available stocks of physical, human, and financial capital, economic infrastructure, resource endowments, and any other characteristics of the physical, social, and economic environment in which production takes place (O'Donnell *et al.* 2008). Therefore, the efficiency measure using SFA or DEA approaches might sometimes lead to inaccurate results, causing the results of the benchmarking frontier models to have a limited value if the difference is not taken into account (Fried *et al.*, 1999; Daraio and Simar, 2007). This situation is perhaps relevant to electricity distribution companies in that there are substantial differences in consumer density and consumer structure across regions. Specifically, the network length is sometimes treated as the most important cost driver and is frequently used in efficiency studies of electricity distribution (Jamassb and Pollitt, 2003) - that is, the network density may reflect the geographical dispersion of the output and the scope of operation which affects an electricity distribution firm's cost frontier. The stochastic metafrontier production approach developed by Battese and Rao (2002) and Rao *et al.* (2003), which compares the efficiency score of firms across different production frontiers, provides a more appropriate methodology to assess the efficiency of electricity distribution firms across regions.

The goals of this paper are to measure the cost efficiency of Taiwan's electricity distribution units and the short-term and long-term optimal scales of the country's electricity distribution industry, attempting to contribute to the existing empirical literature by providing the following distinct types of empirical evidence. First, this study employs the stochastic metafrontier production approach to calculate the efficiency score of electricity distribution firms in Taiwan. While the 24 electricity distribution units in Taiwan belong to one vertically-integrated power company, Taipower Corporation, the operational environment of the 24 regions differs significantly, especially in the aspect of consumer and network density. This implies they might operate under different frontiers,

causing biased estimates when employing the traditional stochastic frontier approach. Second, based on the short-term group-foundation and long-term metafrontier-foundation, this paper calculates the optimal scale of an electricity distribution unit. Following Taiwan's plan to liberalize the local power sector, the regulator (Bureau of Energy) has reconsidered the number of distribution units, and this involves a discussion of optimal scale and optimal firm number in a distribution sector. Our results lend valuable implications for policy reference.

The remainder of this paper is organized as follows. The next section briefly introduces Taiwan's electricity distribution industry and related laws concerning the power sector. Section 3 presents the empirical models for calculating efficiency scores based on the framework of the metafrontier approach and data. Section 4 reports the empirical analyses, including the estimation of cost efficiency and the calculations of optimal scale. Concluding remarks and policy implications are summarized in the final section.

2. Taiwan's Electricity Distribution Sector and the Electricity Act

2.1 Taiwan's Electricity Distribution Sector

Taiwan's electricity system is currently operated by a state-owned monopoly, Taiwan Power Company (Taipower), which is regulated by the Bureau of Energy. This company is highly vertically integrated and comprises three hierarchies: the upstream including various kinds of electricity generation plants, the middle-stream which is the nationwide transportation network, and the downstream which is composed of regional distribution units.

In the distribution sector there are 24 distribution units which are categorized into three classes mainly by the number of customers in terms of household. The distribution units with over 100,000 customers are classified into the first class, while the one with 30,000-100,000 customers is classified into the second class. Finally, a distribution unit

with less than 30,000 customers is classified as the third class. Actually the standard of classification in the 24 distribution units have been used for over 30 years, and most of the distribution units are classified into the first class.

Like most countries, there is a large variance in the number of customers across distribution units, even though Taiwan is a small island. For example, the Tai-chung distributor has 1,173,364 customers, accounting for about 11% of total customers. In contrast, the smallest distributor located in Ma-tzu has only 3,947 customers. The diversity of the 24 distribution units is not only in the number of customers, but also in the size of service territories. The distribution unit with the biggest service territory, Hua-lien, is almost 160 times larger than the smallest in Ma-tzu. In most cases, the distribution units with a smaller service territory are located in urban areas, except for three offshore distribution units. These two factors of the number of customers and service territory combine to form an important feature, network density that can influence distribution units' operating cost. Actually, the difference in network density across 24 distribution units is quite significant.

The energy sale also reveals a regional difference. The average energy sales of Hsin-chu and Tao-yuan distributors are respectively 2,691kWh/month and 2,101 kWh/month per customer, which are about two times larger than the corresponding value of the total average. The number of customers is the main cause of the difference in energy sales, while one alternative reason is the composition of consumer structure. In practice, consumers are classified into two types in Taiwan: household and industrial users. There are many high-voltage (industrial) customers located in the service territory of the above two distribution units and it may result in a higher electricity use in those regions. For example, the famous Hsinchu Industrial Science Park (HSIP) is located in Hsinchu city. Table 1 presents the summary statistics of 24 distribution units in Taiwan.

[Table 1 is inserted about here]

Since the cost structures are sensitive to the network density and consumer structure, it might sometimes lead to inaccurate results if all distribution units are treated as the same group of the production frontier. Accordingly, this study divides the 24 distribution units into two groups - low circuit density units (LCD) and high circuit density units (HCD) - and then implements the estimation of an efficiency score. The definition of circuit density is the number of customer divided by the length of circuit in each distribution unit, which including the concepts of network density and consumer structure in the same index. We use the average circuit density to segment the two groups of LCD and HCD and show the classifications in Table 2.

[Table 2 is inserted about here]

2.2 The Procedure of Deregulation on Electricity Distribution and The Electricity Act

Inspired by deregulation experiences in the power industry of many countries, the liberalization of Taiwan's power industry has been discussed for a long time. Among the measures of deregulation on the power industry, one important policy is to privatize electricity distribution firms and open the market for electricity distribution, because this sector has been recognized as being able to host more than one monopoly firm within a region. The current 24 distribution units belonging to Taipower experience similar cost levels on purchasing electricity power and paying employees' salary. However, they have individual financial statements and they pay performance bonuses to employees, implying that the electricity distribution units act as a monopoly within their operating region, while they have incentives to improve cost efficiency.

To promote market competition in the electricity distribution industry and improve distribution firms' efficiency, the regulator has amended the Electricity Act starting from 1999, aiming to deregulate this industry by privatizing the incumbent firms and allowing free entry. The new version of the amended Electricity Act has been submitted to the Legislative Yuan for review. In the amended Electricity Act, distribution companies are

still viewed as public utilities and regulated by the Bureau of Energy, Ministry of Economic Affairs. More importantly, according to the amended Electricity Act, the distribution sector might advance in the following ways.

First, competition among distribution companies will arise in the marketplace. According to the authority or application, the Bureau of Energy can delimit the operating territory for a vertically-integrated utility or distribution companies to provide service, which can be viewed as franchise regions. However, one franchise region is not restricted to accommodate just one distribution firm. Customers can also ask for electricity supply from generator companies through power wheeling or direct access, implying that intra-region or inter-region competition will happen in the distribution sector.

Secondly, the adjustment of franchise regions will arise in Taiwan, in order to prevent distribution companies from cream-skimming. Since there is regional inequality in terms of population density across the 24 distribution regions, the distribution companies may choose those franchise regions with a higher consumer density or more electricity supplied, inducing a lack of distribution firms within the low density regions. The government authority is therefore seriously considering the readjustment of franchise regions.

Thirdly, the electricity enterprise which operates two or more franchise areas or two different kinds of electricity enterprises should calculate profits and losses individually without going cross-subsidies. This will force the distribution companies to operate as an independent unit. Finally, the electricity price of a vertically-integrated utility and distribution companies should be determined by government authorization. The authority could set a price and chair a fee rate audit committee for handling the price. Since the price regulation of Taiwan's telecommunications industry adopted the idea of incentive regulation, it is often mentioned in the discussion of electricity price regulation.

The amended Electricity Act gives the chance to restructure the electricity industry in Taiwan, including the distribution sector. Under the amended Electricity Act, the regulator

reconsiders the number and size of distribution units in the country. This will involve a discussion of the optimal scale and optimal firm number within the distribution sector.

3. Methodology, Model Specification, and Data

3.1 Stochastic Metafrontier Model

To estimate electricity distribution firms' cost efficiency, we adopt the widely used stochastic cost frontier model for panel data proposed by Battese and Coelli (1992), which is an extension of the original model in Aigner *et al.* (1977). With a firm's cost function following the flexible functional form of a logarithm translog, the empirical model can be expressed as:

$$\ln C_{it}^p = f^p(\ln Q_{it}^p, \ln w_{it}^p, t; \beta^p) + u_{it}^p + v_{it}^p$$

where, $u_{it} \geq 0$; $i = 1, 2, \dots, N$; and $t = 1, 2, \dots, T$ (1)

In this equation, C_{it} refers to the total cost for firm i in year t , Q_{it} is a vector of outputs, and w_{it} is an input price vector. These variables are all taken in a natural logarithmic form, of which N represents the number of production units and T denotes the number of years in this sample. The term v_{it} is assumed to be independently and identically distributed as $N(0, \delta_v^2)$, which is a symmetric disturbance capturing the effect of noise. The term u_{it} is assumed to be independent of v_{it} and to be a non-negative one-sided disturbance following a half-normal distribution, which is included for capturing the effect of inefficiency. Referring to Battese and Coelli (1992), the specification of $u_{it} = u_i \exp[-\eta(t-T)]$ is assumed, where η represents a cross-period adjustment factor. Furthermore, β represents a vector of unknown technological parameters. The superscript p is added for expressing that equation (1) refers to a cost function pooling all the production units i .

The setting of equation (1) implies that the N production units operate under an identical cost function concurrently. Nonetheless, if the production units belong to different technological possibility sets (groups), then an estimation of frontier and technological

parameters β s under the assumption of an identical cost function would be problematic. As indicated by Lau and Yotopoulos (1989, p.242), when certain distinct objective conditions are imposed on different groups of production units, the production units in different groups do not operate under an identical frontier. Herein, the separate cost function settings and estimations should be a more appropriate alternative. The equation (1) is thus adapted as:

$$\ln C_{it}^g = f^g(\ln Q_{it}^g, \ln w_{it}^g, t; \beta^g) + u_{it}^g + v_{it}^g$$

$$\text{where, } u_{it}^g \geq 0; i = 1, 2, \dots, N^g; g = 1, 2, \dots, G; \text{ and } t = 1, 2, \dots, T \quad (2)$$

The superscript g above indicates the g -st technology sets (groups) that production unit i belongs to, while there are G groups in total. Conceptually, in equation (2), $f^g(\cdot)$ denotes that the frontiers of those production units are in the g -st group. A notion is implied that the technological gaps across the groups cannot be surmounted from a relative short-run view. Nonetheless, from a more long-run view, certain distinct objective conditions might be overcome by the effort of production units. All the production units in each group should therefore have potential access to the same technology (Battese and Rao, 2002, Battese *et al.*, 2004). Thus, there is one potential common cost frontier below the existing group frontiers representing the latent technological level - that is, metafrontier.

Figure 1 illustrates the difference between the pooling frontier and metafrontier. In the figure, the points denote actual cost points and the white and black ones are for group 1 and group 2. The thin real line represents the pooling frontier when all the points were treated as the same group. The two dash lines signify the group frontiers respectively when the points are classified into distinct groups. Then the thick real line is the metafrontier which is an envelopment curve of the group frontiers. It is easy to see that the metafrontier would be relatively flexible in nature than the pooling frontier in terms of reflecting the group frontiers (existing technologies). Therefore, the difference between the two kinds of frontiers is a matter of course. For an efficiency study, to ignore the quality of

non-identical frontier and to use the pooling approach directly would suffers the risk of biased estimations.

[Figure 1 is inserted about here]

Then, referring to the original metafrontier production function setting in Battese *et al.* (2004) and the metafrontier cost function extension of Huang and Chiang (2008), the metafrontier could be written as:

$$\ln C_{it}^* = f^*(\ln Q_{it}^*, \ln w_{it}^*, t; \beta)$$

where, $i = 1, 2, \dots, N$; and $t = 1, 2, \dots, T$ (3)

The superscript * is for metafrontier. Based upon the reasoning metafrontier should be an envelopment curve of group frontiers, the parameters of equation (3) could be obtained by solving the following linear programming (LP) or quadratic programming (QP) problems:

$$LP: \text{Min } L^* \equiv \sum_{i=1}^N \sum_{t=1}^T |f^g(\cdot) - f^*(\cdot)|$$

$$s.t.: f^*(\cdot) \leq f^g(\cdot) \quad (4)$$

$$QP: \text{Min } L^{**} \equiv \sum_{i=1}^N \sum_{t=1}^T [f^g(\cdot) - f^*(\cdot)]^2$$

$$s.t.: f^*(\cdot) \leq f^g(\cdot) \quad (5)$$

3.2 Model Specification and Calculation of Optimal Scale

The econometric version of the above cost function with a specification of the Translog functional form can be written as:

$$\begin{aligned} \frac{\ln TC_{it}^H}{\ln PE_{it}^H} &= \beta_0^H + \beta_L^H \left(\frac{\ln PL_{it}^H}{\ln PE_{it}^H} \right) + \beta_K^H (\ln K_{it}^H) + \beta_Q^H (\ln Q_{it}^H) + \beta_T (T) \\ &+ \frac{1}{2} \beta_{LL}^H \left(\frac{\ln PL_{it}^H}{\ln PE_{it}^H} \right)^2 + \frac{1}{2} \beta_{KK}^H (\ln K_{it}^H)^2 + \frac{1}{2} \beta_{QQ}^H (\ln Q_{it}^H)^2 + \frac{1}{2} \beta_{TT}^H (T)^2 \\ &+ \frac{1}{2} \beta_{LK}^H \left(\frac{\ln PL_{it}^H}{\ln PE_{it}^H} \right) (\ln K_{it}^H) + \beta_{LQ}^H \left(\frac{\ln PL_{it}^H}{\ln PE_{it}^H} \right) (\ln Q_{it}^H) + \beta_{LT}^H \left(\frac{\ln PL_{it}^H}{\ln PE_{it}^H} \right) (T) \end{aligned}$$

$$\beta_{KQ}^H (\ln K_{it}^H) (\ln Q_{it}^H) + \beta_{KT}^H (\ln K_{it}^H) (T) + \beta_{QT}^H (\ln Q_{it}^H) (T) \quad (6)$$

Here, superscript H is an indicator of the cost frontiers; $H = "p", "g" \text{ or } "*" ,$ respectively denoting the frontiers are for the pooling frontier of equation (1), the group frontier of equation (2), and metafrontier of equation (3). In equation (6), linear homogeneity in input prices is imposed by dividing money values by the price of the input power (PE), where PE is averaged weighted price for electricity selling, weighted by high-voltage and low-voltage power. Under the monopoly⁴ and vertically-integrated structure, cost-based pricing is set by regulator. Since the relation between cost and price of electricity is proportional, the averaged weighted price can be a proxy of input price. Here, TC is total annual costs, including labor, capital and energy costs, PL is average annual labor price per employee, Q is annual electricity supply in GWh, and K is quasi-fixed capital in the short-run cost function (see Caves, Christensen and Swanson, 1981; Schankerman and Nadiri, 1986; Nelson, 1985).

As for the calculation of the optimal production scale, the fundamental theory of minimum efficient scale (MES) in Industrial Economics is used. This study defines the output level of MES by the minimum point of the long-run average cost function that can be assessed by the following derivative:

$$\frac{\partial \ln AC}{\partial \ln Q} = \frac{\partial \ln (TC/Q)}{\partial \ln Q} = \frac{\partial \ln TC}{\partial \ln Q} - 1 = 0 \Rightarrow \frac{\partial \ln TC}{\partial \ln Q} = 1 \quad (7)$$

Accordingly, the unknown and desired optimal output level can be simply obtained by calculating the fitted value of Q in equation (8) derived from the estimation of equation (6).

$$\frac{\partial \left(\frac{\ln TC_{it}^H}{\ln PE_{it}^H} \right)}{\partial \ln Q_{it}^H} = \beta_Q^H + \beta_{QQ}^H (\ln Q_{it}^H) + \beta_{LQ}^H \left(\frac{\ln PL_{it}^H}{\ln PE_{it}^H} \right) + \beta_{KQ}^H (\ln K_{it}^H) + \beta_{QT}^H (\ln T) = 1 \quad (8)$$

⁴ Although there are some IPPs in Taiwan's electricity industry, all electricity produced by them must be sold to Taipower, and they can be viewed as Taipower's power plants in some respects.

The data used in this study contain 24 electricity distribution units in Taiwan over the 1997-2002 period, yielding 144 observations. Table 3 shows the summary statistics of variables for the cost function. Because of the concern that the 24 distribution units might be in a different frontier, a further discussion is needed for the characteristics of the observed samples. As seen from the table, we present that the differences are significant for all variables.

[Table 3 is inserted about here]

4. Empirical Analysis

4.1 Estimations of Cost Efficiency

This subsection constructs the cost frontiers. On the basis of equation (6), we consider two sets of a hypothetic arrangement. One is that all the distribution units use the same technology and face an identical frontier. The estimates are displayed in the regression ‘pooling’ of Table 4. The other one is that the LCD and HCD units face different operational environments and operate under distinct frontiers. Table 4 respectively reports the estimates of the two groups in the regressions ‘L group’ and ‘H group’ for low circuit density and high circuit density units.

[Table 4 is inserted about here]

As observed from the table, roughly half of the estimated coefficients are statistically significant, indicating that there actually exists a certain functional relationship among the dependent and explanatory variables, in line with the theoretical expectation. In the three regressions, the estimated parameters γ are all above 0.9. This reflects that much (at least 90%) of the variation in the composite error term is due to the inefficiency component (Coelli *et al.*, 2005).

The bottom of Table 4 reports the log-likelihood ratios (LR) of the regressions, which enable us to examine whether the LCD and HCD units operate under different frontiers. Referring to the operation in Battese *et al.* (2004), a LR test is then conducted. The

calculated LR statistic is 73.355, which is significant at the 1% statistical level. This result strongly suggests that the distribution units in the two groups operate under different technological frontiers. Thus, the preferred models should be those that separately estimate the frontiers by segmenting the data from the LCD and HCD regions. As for the metafrontier, on the basis of equation (6), the right column of Table 4 demonstrates the estimations using linear programming, while the standard errors obtained by a bootstrapping approach are also provided for reference.⁵

Before discussing the dynamics of cost efficiency for electricity distribution firms, we now look at the estimated cost efficiency obtained from different models. Table 5 represents the comparison of estimation results under various assumptions of pooling-foundation and meta-foundation. In the case of pooling-foundation which treats all units operating under the same technology frontier, the average cost efficiency score is 0.9385. Meanwhile, through the difference test we know that the score is statistically significant higher than the corresponding value of 0.8667 obtained from the meta-foundation estimation. The reasons for the lower efficiency scores of metafrontier foundation might be two fold: (i) the meta-foundation considers the technological gap in the efficiency measures, but the pooling-foundation does not; (ii) the pooling foundation potentially treats all units face the same technological frontier, regardless whether the units belong to the same production set. Therefore, the miss-specification might incur the frontier construction bias toward some part of observations. Thus, to a certain extent it implies that the pooling-foundation over-estimate the efficiency scores.

Moreover, the average cost efficiency score of the LCD group is 0.9391, slightly higher than that of the HCD group (0.9380) in the pooling-foundation model. This result seems to contradict with the common knowledge that high circuit density units usually have higher cost efficiency due to the advantage of network externality, but the difference is not

⁵ Most of the estimated parameters for the LCD frontier, HCD frontier and metafrontier conform to the regular conditions of the cost function.

statistically significant. On the other hand, as we treat low and high circuit density units operating under different technologies, the estimates obtained from the metafrontier model show that the average cost efficiency score for the HCD and LCD groups are 0.8797 and 0.8512, respectively. The difference test is significant at the 1% statistical level, indicating that the HCD group is more efficient than the LCD group. This finding is consistent with findings in existing studies discussed in the previous section whereby network density serves as an important factor determining efficiency for the electricity distribution industry. More importantly, the reverse result of the meta-foundation model highlights the importance of model specification for firms operating under different technology frontiers.

[Table 5 is inserted about here]

Turning to a focus on the cost efficiency of electricity distribution firms over the past decade, Figure 2 presents the scatter plot of mean efficiency scores during the period spanning 1997-2002. This figure shows that Taiwanese electricity distribution firms experienced a slightly decreasing trend on cost efficiency annually, which fell from 0.8847 in 1997 to 0.8471 in 2002, reaching an average of 0.8667 during the sample period. Although the mean efficiency score (0.8667) is quite high, indicating only a potential cost savings of 13.33% on average, the continuous decrease is a discouraging result that Taiwanese electricity distribution firms have worsened rather than improved their efficiency. Technological progress is widely recognized to be very slow within the electricity distribution industry. Given that the cost structure is unchanged in the short run, the efficiency score may depend heavily on the firm's output. Therefore, the decreasing efficiency might be attributed to external macroeconomic shocks. Actually, there are some significant macroeconomic shocks that impact negatively on the demand for electricity power during that period – for example, the Asian financial crisis in 1998 and the 921 earthquake in 1999.⁶ In 2001, the 911 terrorist attacks in the U.S. also shocked Taiwan's

⁶ The 921 earthquake happen in September 21 1999, and this earthquake measured 7.3 on the Richter scale and caused 2,416 deaths and 44,338 houses to be completely destroyed.

economy, because U.S. is the main destination for Taiwanese high-tech product exports. The energy sales in these years really show an abnormal growth. As shown in the right side of figure 2, the growth rates of energy sales in 1999 and 2001 are much lower than the other period, revealing the impact of external macroeconomic shocks.

[Figure 2 is inserted about here]

Figure 2 also plots the trends of mean efficiency scores for high and low circuit density units, respectively. It is apparent to see that both of these two groups experienced a similar decreasing trend on efficiency performance. In the high circuit group, the mean efficiency score decreased from 0.8975 in 1997 to 0.8590 in 2002, with an average efficiency of 0.8797 during that period. On the other hand, the corresponding values for the low circuit group were 0.8696 and 0.8331, reaching an average of 0.8512. Though the average mean efficiency score of HCD is slightly higher compared to the LCD units (85.12% vs. 83.31%), this difference is statistically significant (Table 6). The feature of high circuit density enables distribution firms to save operating costs on circuit layout and decreases the electricity wasted during the transportation process. HCD firms therefore exhibit a significantly higher efficiency on average.

As mentioned previously, the regulatory practices in the electricity market are mainly based on benchmarking - that is, based on the efficiency ranking among distribution units. It indicates the importance of the reliable ranking of the efficiency score across firms. We further compare the ranking obtained from different models and display the results in Table 6. The correlation coefficients of the two series of estimates, in terms of mean efficiency score and ranking, are 0.623 and 0.579, respectively. This moderate relationship between the two series of estimates indicates that the regulatory practices may encounter the risk of an inappropriate policy if the regulatory authority exerts regulatory measures based on the traditional pooling-foundation model. Looking further at an individual firm's ranking, the change of ranking among the top-four firms seems not to be substantial,

meaning that the benchmarking firm or benchmarking group may not change between these two estimations. However, the change in ranking is quite significant for other firms, except for L9, indicating the importance of the methodology adopted to estimate the distribution units' average efficiency scores.

[Table 6 is inserted about here]

4.2 Calculation of Optimal Scale

We return to the first essential question this study looks at: how many segmented markets should be classified in Taiwan? In other words, what is the optimal scale for an electricity distribution firm in Taiwan? Three series of estimates which are based on pooling-foundation, group-foundation, and meta-foundation are calculated in this study. In the pooling-foundation, the optimal scale is calculated under the assumption that all observed units belong to the same frontier. When firms operate under different frontiers, the optimal scale of different groups should be calculated separately. Therefore, the methodology of group-foundation separates observed units into LCD and HCD groups. The corresponding figure represents the short-term optimal scale in the short-run cost function.

Finally, the conception of metafrontier starts from a more long-run view that all the distribution units in each group should have potential access to the same technology. Therefore, there is one potentially common frontier above the existing group frontiers, representing the latent technological level. The optimal scale calculated under meta-foundation can be regarded as a long-term value. Table 7 reports the corresponding values of optimal scale and the adjustment path to the short-term and long-term optimal scales.

[Table 7 is inserted about here]

In the pooling-foundation model, we obtain an optimal scale of 23,044 GWh for an electricity distribution unit derived from equation (8). Compared with the current average

outputs of electricity distribution of 5,662 GWh, the optimal scale is nearly 4 times larger than the current mean output, implying that the optimal number of electricity distribution units is about eight firms as calculated by the total electricity consumption in 2007 (186,998 GWh). However, as shown in column 1 of Table 7, the current average scale of HCD and LCD firms differ substantially (8,759 vs. 2,002 GWh) due to the differences in geographical condition and consumer structure. This implies that the above argument is perhaps biased due to the differences in circuit density, and firm heterogeneity is not taken into account.

Considering the existence of different groups in the group-foundation model, the derived short-run optimal scale of the HCD and LCD groups are 18,638 and 18,041 GWh, respectively. Both of these two figures are smaller than that obtained from the pooling-foundation model (23,044 GWh). They are about two and nine times larger than the corresponding scale of the HCD and LCD firms. If the regulatory authority attempts to deregulate this industry and creates a free entry market, then the electricity distribution market can accommodate a total of ten firms. However, the number of segmented markets based on the short-run optimal scale is hard to realize in practice, because the limitation of terrain features may prevent some HCD and/or LCD regions to be treated as an individual market.

The plausible measure to divide the optimal number of markets refers to the long-term optimal scale. According to the estimates obtained from the metafrontier model that treats HCD and LCD firms operating under different frontiers but sharing a common long-term technological frontier, the calculated output of the long-term optimal scale is 12,139 GWh. This magnitude is much smaller than those corresponding values obtained from the pooling-foundation and group-foundation approaches. Under the long-term concept, the optimal number of electricity distribution firms is about 15, based on the electricity consumption in 2007. The long-term optimal scale should be calculated according to the

estimated future consumption on electricity. Assuming a 3% growth rate of electricity consumption, the optimal number of electricity distribution firms reaches only 16 or 17 firms based on the electricity consumption in 2017.⁷

Drawn from the above analysis, the current scale of distribution units is smaller than the long-term optimal scale, indicating that there are too many distribution units in Taiwan's electricity distribution industry. The regional integration of distribution units should be helpful for efficiency improvement, but the adjustment must consider the limitations of geographical features and consumer structure. The question of how to classify individual operating regions is beyond the scope of this study.

5. Conclusions

Regulatory reform and incentive-based regulation of distribution utilities have become more common in many countries. How the regulator can reward or punish companies accordingly is heavily dependent on a reliable measure of firms' inefficiency scores in the benchmarking method. However, the efficiency measure using traditional approaches of SFA or DEA might sometimes lead to inaccurate results when heterogeneity among firms is significant. The heterogeneity, sourced from factors that influence the operational environment, might cause the observed units to operate under different frontiers. This paper aims to estimate the cost efficiency and optimal scale of Taiwan's electricity distribution units corresponding to the deregulation policy on the electricity distribution policy. According to the important feature of this industry's circuit density, we classify 24 distribution units into two different groups - low circuit density and high circuit density - and then employ the technique of the metafrontier stochastic model to estimate the efficiency score.

Empirical results show that the traditional stochastic frontier approach encounters an

⁷ During the 2004-2007 period, the growth rate of electricity consumption was about 2.8%. Moreover, the estimated electricity consumption is 319,834 GWh for 2017, assuming a 3% annual growth rate.

overestimation bias on efficiency. In the previous studies of cost efficiency estimation in the network industry, the problem of “mutually consistent” different models has been pointed out to be an important drawback of the benchmarking method (Farsi and Filippini, 2004). This paper further indicates the problem that firms might operate under different frontiers, and the technique of metafrontier should be employed in a benchmark comparison.

The mean efficiency score obtained from the metafrontier approach is about 86.67% over the 1997-2002 period, indicating that the cost efficiency is quite high for electricity distribution firms in Taiwan. This high efficiency may arise from the similar cost structure across distribution firms, because they pay the same price to buy electricity from the monopoly company, Taipower. Although there is only a potential cost savings of 13.33%, on average, the continuous decrease in cost efficiency is worth noting for these electricity distribution firms.

In this paper, cost efficiency of Taiwan’s electricity distribution units and the short-term and long-term optimal scales of the country’s electricity distribution industry have been measured after considering the diversity of 24 distribution units, and these results have different policy implication in the stage of deregulation. First, in order to prevent distribution companies from cream-skimming, the adjustment of franchise regions will arise in Taiwan, and it means that the estimation of optimal scale must be proceeded before deregulation. Moreover, the estimated number of firms operating under the short-term and long-term optimal scale is 10 and 16 respectively, which are lower than the current number of distribution units of 24, implying that there are too many electricity distribution firms in Taiwan. The firm scale which is below the optimal scale is one possible factor causing cost inefficiency for electricity distribution firms in Taiwan. Therefore, integration of existing 24 distribution units might helpful in efficiency improvement in Taiwan’s electricity market.

However, how to classify individual operating regions for an optimal scale of distribution firm is beyond the scope of this study. It is not difficult to estimate the optimal number of electricity distribution firms according to economic analysis. In practice, the layout of an electricity transportation network is restricted by land forms, such as the barriers from high mountains or the ocean. Therefore, the practical number of optimal-scale firms should also consider the limitation of geographical features from the standpoint of technology.

Secondly, after liberalization of distribution industry, the electricity distribution utilities will still have strong market power within their service territories, indicating a rate regulation by the authorities is necessary. Based on the benchmarking method, regulator can reward or punish companies accordingly is heavily dependent on a reliable measure of firms' inefficiency scores, therefore, the reliability of the efficiency score is particularly crucial in regulatory practices. When distribution units or companies operate under different frontiers, like Taiwan's distribution industry, the stochastic metafrontier production approach provides a more appropriate methodology to assess the efficiency of electricity distribution firms across regions.

Although Taiwan is a small island, the differences between 24 distribution units are apparent, and can be a good example to compare the results between traditional SFA or DEA approaches and metafrontier model. Turning to the distribution industry of some OECD countries, the differences also exist especially in cross-country comparison. The size and scale of distribution utilities between some OECD countries reveal a noticeable difference. Therefore, the compare of these distribution utilities should notice that if they are in the same frontier.

Reference

- Agrell, P.J., P. Bogetoft and J. Tind (2005), DEA and Dynamic Yardstick Competition in Scandinavian Electricity Distribution, *Journal of Productivity Analysis*, 23, 173-201.
- Bagdadioglu, N., C.M. Waddams and T.G. Weyman-Jonse (1996), Efficiency and Ownership in Electricity Distribution: A Non-parametric Model of the Turkish Experience, *Energy Economics*, 18, 1-23.
- Battese, G.E. and D.S.P. Rao (2002), Technology Gap, Efficiency and a Stochastic Metafrontier Function, *International Journal of Business and Economics*, 1, 87-93.
- Battese, G.E., D.S.P. Rao and C.J. O'Donnell (2004), A Metafrontier Production Function for Estimation of Technical Efficiencies and Technology Potentials for Firms Operating under Different Technologies, *Journal of Productivity Analysis*, 21, 91-103.
- Burn P. and T.G. Weyman-Jonse (1996), Cost Function and Cost Efficiency in Electricity Distribution: A Stochastic Frontier Approach, *Bulletin of Economic Research*, 48, 41-64.
- Caves, D.W., L.R. Christensen and J.A. Swanson (1981), Productivity Growth, Scale Economies and Capacity Utilization in U.S. Railroad 1955-1974, *American Economic Review*, 71, 994-1002.
- Chen, T.Y. (2002), An Assessment of Technical Efficiency and Cross-Efficiency in Taiwan's Electricity Distribution Sector, *European Journal of Operation Research*, 137, 421-433.
- Coelli, T., D.S.P. Rao, C.J. O'Donnell, and G.E. Battese (2005), *Introduction to Efficiency and Productivity Analysis*, 2nd edition, Springer, Heidelberg.
- Daraio, C. and L. Simar (2007), *Advanced Robust and Nonparametric Methods in Efficiency Analysis - Methodology and Applications*, Kluwer Academic Publishers, Dordrecht.
- Erbetta, F. and L. Rappuoli (2008), Optimal Scale in the Italian Gas Distribution Industry

- Using Data Envelopment Analysis, *The International Journal of Management Science*, 36, 325-336.
- Farsi, M. and M. Filippini (2004), Regulation and Measuring Cost-Efficiency with Panel Data Model: Application to Electricity Distribution Utilities, *Review of Industrial Organization*, 25, 1-19.
- Filippini, M. and Wild, J. (2001), Regional differences in Electricity Distribution Costs and Their Consequences for Yardstick Regulation of Access Prices, *Energy Economics*, 23, 477-488.
- Filippini, M., N. Hrovatin and J. Zoric (2004) Efficiency and Regulation of the Slovenian Electricity Distribution Companies, *Energy Policy*, 32, 335-344.
- Filippini, M., N. Hrovatin and J. Zoric (2008) Cost Efficiency of Slovenian Water Distribution Utilities: an Application of Stochastic Frontier Methods, *Journal of Productivity Analysis*, 29, 169-182.
- Fried, H.O., S.S. Schmidt and S. Yaisawarng (1999), Incorporating the Operating Environment into a Nonparametric Measure of Technical Efficiency, *Journal of Productivity Analysis*, 12, 249-267.
- Giannakis, D., T. Jamasb and M. Pollitt (2005), Benchmarking and Incentive Regulation of Quality of Service: An Application to the UK Electricity Distribution Networks, *Energy Policy*, 33, 2256-2271.
- Growitsch, C., T. Jamasb and M. Pollitt (2008) Quality of Service, Efficiency and Scale in Network Industry: an Analysis of European Electricity Distribution, *Applied Economics*, forthcoming.
- Hattori, T. (2002), Relative Performance of U.S. and Japanese Electricity Distribution: An Application of Stochastic Frontier Analysis, *Journal of Productivity Analysis*, 18, 269-284.
- Hattori, T., T. Jamasb and M. Pollitt (2005), Electricity Distribution in the UK and Japan:

- A Comparative Efficiency Analysis 1985-1998, *Energy Journal*, 26, 23-47.
- Hjalmarsson, L. and A. Veiderpass (1992), Efficiency and Ownership in Swedish Electricity Retail Distribution, *Journal of Productivity Analysis*, 3, 7-23.
- Huang, T.H. and L.C. Chiang (2008), Technical Efficiency and Technology Gaps in European Commercial Banks, the 9th Empirical Economics Conference 2008, Taipei, Taiwan.
- Jamasb, T. and M. Pollitt (2001), Benchmarking and Regulation: International Electricity Experience, *Utilities Policy*, 9, 107-130.
- Jamasb, T. and M. Pollitt (2003), International Benchmarking and Regulation: An Application to European Electricity Distribution Utilities, *Energy Policy*, 31, 1609-1622.
- Nelson, R.A. (1985), Return to Scale from Variable and Total Cost Functions, Evidence from the Electric Power Industry, *Economic Letters*, 18, 271-276.
- O'Donnell, C.J., D.S.P. Rao and G.E. Battese (2008), Metafrontier Frameworks for the Study of Firm-Level Efficiencies and Technology Ratios, *Empirical Economics*, 34(2), 231-255.
- Pacudan, R. and E. de Guzman (2002), Impact of Energy Efficiency Policy to Productive Efficiency of Electricity Distribution Industry in the Philippines, *Energy Economics*, 24, 41-54.
- Rao, D.S.P., C.J. O'Donnell and G.E. Battese (2003), Metafrontier Function for the Study of Interregional Productivity Differences, Center for Efficiency and Productivity Analysis, Working Paper.
- Rao, D.S.P. (2006), Metafrontier Frameworks for the Study of Firm-Level Efficiencies and Technology Gaps, 2006 Productivity and Efficiency Seminar, Taipei, Taiwan.
- Schankerman, M. and M.I. Nadiri (1986), A Test of Static Equilibrium Models and Rates of Return to Quasi-fixed Factors, with an Application to the Bell System, *Journal of*

Econometrics, 33, 97-118.

Salvanes, K.G. and S. Tjoota, (1994), Productivity Differences in Multiple Output Industries: An Empirical Application to Electricity Distribution, *The Journal of Productivity Analysis*, 5, 23-43.

Zhang, Y. and R. Bartels (1998), The Effect of Sample Size on the Mean Efficiency in DEA with an Application to Electricity Distribution in Australia, Sweden and New Zealand, *Journal of Productivity Analysis*, 9, 187-204.

Table 1 Summary Statistics of 24 Distribution Units in Taiwan

Name of distribution unit	Energy sale (kWh/year)	Number of customers (A)	Area of service territory (km ²) (B)	energy sale per customer (kWh/month)	Customer density (A/B)
Chi-lung	2,708,758,022	334,398	751	675	445
Taipei city	9,295,922,748	597,056	63	1,297	9,552
South Taipei	7,236,637,846	805,519	885	749	910
North Taipei	4,786,277,928	430,288	430	927	1,000
West Taipei	9,660,297,104	671,762	542	1,198	1,239
Tao-yuan	19,641,497,533	779,126	1,228	2,101	634
Hsin-chu	11,768,707,930	364,458	1,531	2,691	238
Miao-li	4,637,119,647	264,782	1,878	1,459	141
Tai-chung	12,810,009,115	1,173,364	2,250	910	521
Nan-tou	2,651,711,398	314,678	4,497	702	69
Chang-hua	7,506,849,700	715,956	1,078	874	664
Yun-lin	3,478,977,069	459,661	1,291	631	356
Chia-yi	3,130,679,142	445,436	1,962	586	227
Hsin-yin	2,791,097,227	212,678	865	1,094	245
Tai-nan	9,745,711,752	774,514	1,322	1,049	585
Kao-hsiung	11,599,187,219	803,012	517	1,204	1,553
Foun-shan	10,886,268,092	564,271	2,422	1,608	232
Ping-tung	3,433,445,792	492,808	2,970	581	165
Tai-tung	714,046,287	105,096	3,515	566	30
Hua-lien	1,900,115,553	151,508	4,600	1,045	32
Yi-lan	2,701,107,339	222,351	2,001	1,012	111
Peng-hu	291,234,445	39,571	123	613	322
Kin-men	174,483,909	19,449	149	748	130
Ma-tzu	48,896,210	3,947	29	1,032	137

Table 2 LCD and HCD for 24 Distribution Ynits

Low circuit density(LCD)		High circuit density(HCD)	
L1	Chia-yi	H1	Chi-lung
L2	Ping-tung	H2	Taipei city
L3	Tai-tung	H3	Tao-yuan
L4	Hua-lien	H4	Hsin-chu
L5	Peng-hu	H5	Tai-chung
L6	Nan-tou	H6	Chang-hua
L7	Yun-lin	H7	Tai-nan
L8	Hsin-yin	H8	Kao-hsiung
L9	Miao-li	H9	Yi-lan
L10	Kin-men	H10	South Taipei
L11	Ma-tzu	H11	North Taipei
		H12	West Taipei
		H13	Foun-shan

Table 3 Summary Statistics of Variables for the Cost Function

Variables	Amount			Measurement	Definition
	Pool	LCD ^a HCD ^b	Diff. test ^c		
TC	35,918.862	15,531.869 53,169.394	170.068***	Million NT\$	Total cost
PE	2.259	2.294 2.229	11.467***	NT per kWh	Averaged weighted price for electricity selling
PL	1,412.592	1,390.338 1,431.421	3.790*	Thousand NT\$ per employee	Average wage rate
K ^d	12,512.373	7,040.416 17,142.491	161.643***	Million NT\$	Quasi-fixed capital
Q	5,662.250	2,002.273 8,759.154	151.809***	Millions kWh	Annually total electricity supply

Notes: a: Low circuit density units (group dummy = 0). b: High circuit density (group dummy = 1). c: the difference test employed is the one-way ANOVA test with F-statistics, while ***, **, and * denote coefficient significance at 1%, 5% and 10%, respectively. d: capital data is used in book value. e: all of nominal variables have been deflated into real variables.

Table 4 Frontier Estimations

Variables	L group		H group		Pooling ^a			Meta (LP) ^d	
	Coefficient	Std. Err	Coefficient	Std. Err	Coefficient	Std. Err	Coefficient	Std. Dev.	
Constant	4.4816	3.1736	15.0024 ***	5.7493	-5.8519 ***	2.0369	-0.6126	14.2202	
PL/PE	-0.9700	0.8518	-1.9481 *	1.0747	2.1077 ***	0.6068	0.3756	4.1657	
K	0.0958	0.3920	-0.9885	1.0985	0.5069 ***	0.2180	0.6720	1.4169	
Q	0.7512 ***	0.3334	0.2751	0.7301	0.6220 ***	0.1853	0.2638	0.9988	
T	-0.0130	0.0092	-0.0216 ***	0.0104	-0.3031 ***	0.0681	-0.0082	0.0181	
PL/PE2	0.2370 ***	0.1117	0.4624 ***	0.1515	-0.2919 ***	0.0907	0.1939	0.6231	
K2	0.2023 ***	0.0574	0.2893 *	0.1580	0.2169 ***	0.0359	0.4674	0.1889	
Q2	0.2064 ***	0.0276	0.2133 ***	0.0759	0.2268 ***	0.0147	0.3412	0.0589	
T2	0.0001 ***	0.0000	0.0000	0.0000	-0.0071 ***	0.0010	0.0000	0.0000	
PL*K	-0.0235	0.0704	-0.0807	0.1350	-0.0654	0.0415	-0.2824	0.2065	
PL*Q	-0.0453	0.0552	-0.0339	0.0839	0.0140	0.0326	0.1271	0.1587	
PL*T	-0.0001	0.0016	-0.0002	0.0013	0.0506 ***	0.0108	-0.0009	0.0023	
K*Q	-0.1684 ***	0.0365	-0.1182	0.0992	-0.2112 ***	0.0217	-0.3488	0.1099	
K*T	0.0008	0.0008	0.0035 ***	0.0016	0.0020	0.0024	0.0022	0.0012	
Q*T	0.0008	0.0006	-0.0011	0.0011	-0.0001	0.0016	-0.0004	0.0005	
Sigma	0.0077 ***	0.0033	0.0218 ***	0.0019	0.0056 ***	0.0019	-	-	
Garma	0.9890 ***	0.0058	0.9950 ***	0.0012	0.9897 ***	0.0041	-	-	
Eta	-0.0761 ***	0.0179	-0.0626 ***	0.0184	0.0095	0.0189	-	-	
No. of obs.	66		78		144			144	
L-LR $\chi^2(0.05, 14)^b=23.68$	190.6710***		210.5080***		437.8567***			-	
L-LR $\chi^2(0.05, 18)^c=28.87$			73.3554***					-	

Notes: ***, ** and * denote coefficient significant at 1%, 5% and 10%, respectively. The estimated results approximately satisfy the required regular conditions for cost function. a: All units are used to estimate the stochastic frontier. b: Likelihood ratio test; H0: all the $\beta = 0$; H1: at least one of the β is not 0. c: Likelihood ratio test; H0: the frontiers of the units are identical; H1: the frontiers of units in different groups are distinct. The LR statistic is defined by $\lambda = -2 \{ \ln[L(H0)] - \ln[L(H1)] \}$, where, the $\ln[L(H0)]$ is the value of the log likelihood function for the frontier estimated by pooling all the units, while the $\ln[L(H1)]$ is the sum of the values of the log likelihood functions for the two groups frontiers. d: Estimates with linear programming approach. The Standard deviations are obtained by the bootstrapping approach.

Table 5 Cost Efficiency Estimation for the Electricity Supply in Taiwan

Units	Pooling-foundation			Meta-foundation		
	CE estimates	Std. Dev.	Diff. Test.	CE estimates	Std. Dev.	Diff. Test.
LD	0.9391	0.0351	0.0261	0.8512	0.0587	10.4046***
HD	0.9380	0.0405		0.8797	0.0473	
Average	0.9385	0.0379	-	0.8667	0.0546	-
Diff. test.	168.280***					

Notes: ***, **, and * denote statistical significance at 1%, 5% and 10% level, respectively.

a: One-way ANOVA test is adopted.

Table 6 Technical Efficiency Estimation for 24 Distribution Units

Units	Name of distribution unit	CE estimates	Efficiency ranking of meta-foundation
L1	Chia-yi	0.8066	21 (11)
L2	Ping-tung	0.8352	16 (5)
L3	Tai-tung	0.8638	13 (6)
L4	Hua-lien	0.7967	24 (19)
L5	Peng-hu	0.9068	5 (10)
L6	Nan-tou	0.8342	17 (16)
L7	Yun-lin	0.839	15 (13)
L8	Hsin-yin	0.8062	22 (20)
L9	Miao-li	0.7968	23 (23)
L10	Kin-men	0.8873	8 (12)
L11	Ma-tzu	0.991	1 (2)
H1	Chi-lung	0.8204	19 (7)
H2	Taipei city	0.8619	14 (8)
H3	Tao-yuan	0.8713	10 (21)
H4	Hsin-chu	0.8299	18 (24)
H5	Tai-chung	0.9235	4 (9)
H6	Chang-hua	0.8676	11 (14)
H7	Tai-nan	0.8843	9 (15)
H8	Kao-hsiung	0.892	7 (17)
H9	Yi-lan	0.8085	20 (18)
H10	South Taipei	0.9687	2 (1)
H11	North Taipei	0.9055	6 (3)
H12	West Taipei	0.9389	3 (4)
H13	Foun-shan	0.8641	12 (22)
Average		0.8667	

Notes: The number in brackets presents the efficiency ranking under pooling foundation.

Table 7. Average Current and Optimal Scale Calculations for the Electricity Supply in Taiwan

Units	Current scale	Pooling-foundation		Group-foundation			Meta-foundation		
		Optimal scale	Scale adjustment	Optimal scale	Scale adjustment	Deviation	Optimal scale	Scale adjustment	Deviation
	(1)	(2)	(3)=(2)-(1)	(4)	(5)=(4)-(1)	(6)=(2)-(4)	(7)	(8)=(7)-(1)	(9)=(2)-(7)
LD	2,002	23,044	21,042	18,041	16,039	5,003	12,139	10,136	10,905
HD	8,759		14,285	18,638	9,879	4,406		3,379	

Notes: The misspecification deviation under the pooling foundation calculation of optimal scale.

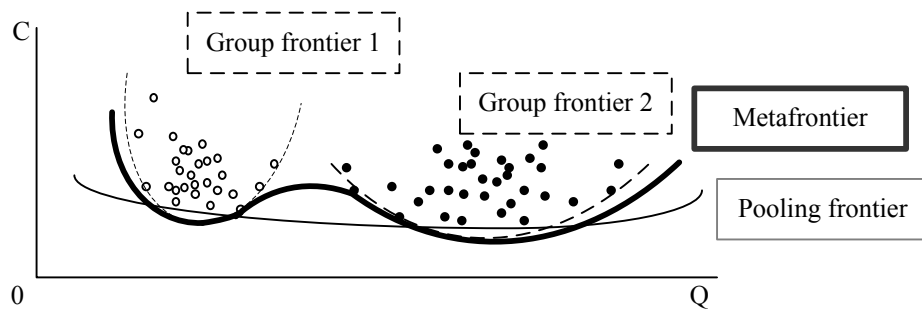


Figure 1 Graphical Explanation on the Difference between Pooling Frontier and Metafrontier.

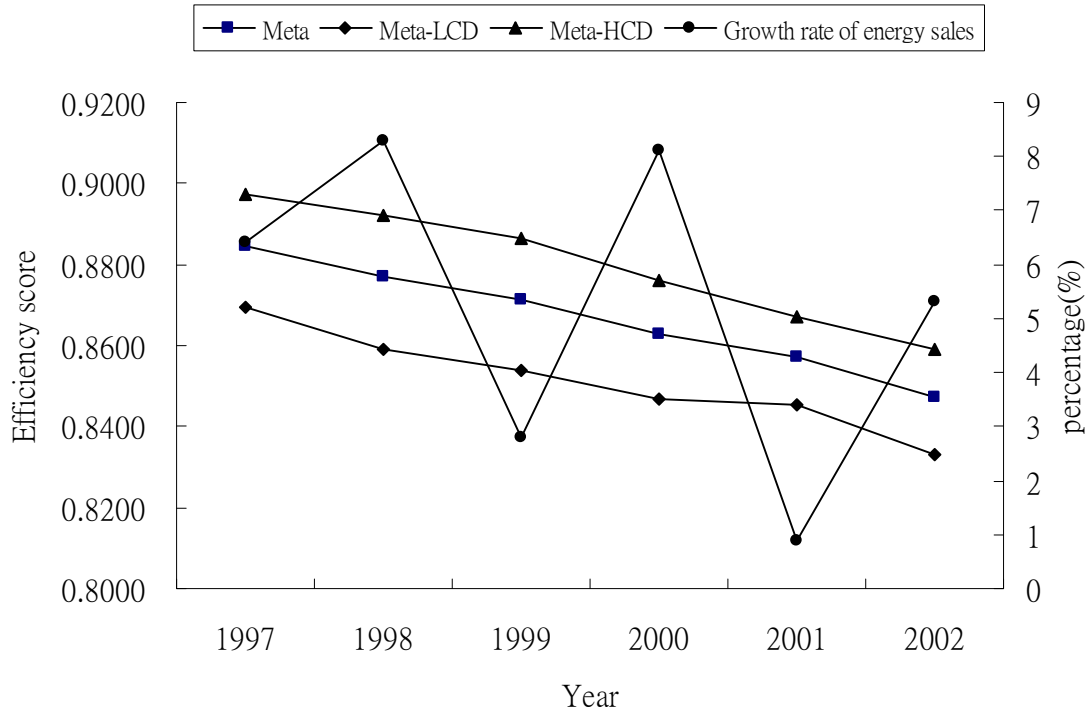


Figure 2 Efficiency Score Dynamics of Electricity Distribution Firms in Taiwan