Measuring the Efficiency of Regional Economic Systems–Applying Network Slack-Based Measure DEA to Taiwan’s Counties/Cities

Chih-Cheng Chen*

Abstract

In this study, we modify the slack-based measure network data envelopment analysis (SBM network DEA) approach proposed by Kao (2014b) to calculate the efficiency of regional economic systems in Taiwan’s counties/cities during the period 2003~2014. For applying the SBM network DEA model to analyze the efficiency of the economic system, we divide the regional economic system of Taiwan’s counties/cities into a series of five stages—entrepreneurship, sustainability, operation, distribution, and consumption—and include the shared inputs and undesirable variables in the analysis framework. Our findings indicate that the average efficiency scores at the operation and consumption stages in the economic systems are the highest and lowest, respectively. We also observe a gap between the average efficiency at the entrepreneurship and operation stages between the urban and rural areas. Besides, gaps

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exist between the service and non-service counties/cities at the sustainability, operation, allocation, and consumption stages in Taiwan's counties/cities. Finally, we identify wider efficiency differences among the regions in all the stages. Local officials responsible for the economic development can find out their own advantage and disadvantage stages and select the prior stages to improve the system performance according to our empirical results.

Keywords: Regional Efficiency, Economic System, Slack-Based Method (SBM), Network Data Development Analysis (Network DEA)

JEL Classification: R58, H83, P51

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I. Introduction

Intense global competition is driving counties or regions in a country to seek unique approaches to increase their competitiveness and competence, especially from the economic perspective (Porter, 1998; Chen, 2017). One such method is to apply various indices to measure the economic performance of a country to assess the advantages and disadvantages of using the inputs and producing outputs simultaneously. However, previous studies consider the economic sector as a black box, regardless of the perspective of a country or region, and focus only on the overall economic and environmental performance. None of them have investigated the inner structure of an economic sector or proposed a transition structure among the economic variables. For example, to measure regional economic development or environmental efficiency, most studies use employment and capital as basic inputs; regional GDP and total amount of CO_2 emissions are the basic desirable and undesirable outputs, respectively (Halkos and Tzeremes, 2011; Halkos and Tzeremes, 2013; Goto et al., 2014; Halkos et al., 2016; Shao and Wang, 2016). In fact, starting new firms could not only affect inputs but also have a direct impact on operational sustainability. Besides, allocation of total production to residents' income is always an important administrative duty/task of the government. In other words, the research framework and selected variables mentioned above are only related to some parts of the economic administration process. Thus, from the perspective of the government, information extracted from previous studies may be not comprehensive enough because it is challenging to investigate the operational performance of the different stages in an economic system. Therefore, the de-structuring of transmission mechanisms within an economic system and investigating the corresponding efficiencies of the structure could help overcome these problems.

The efficiencies of the different stages in the economic system can be calculated by applying network data envelopment analysis (network DEA). The DEA technique measures the relative efficiency of a system, taking into account its internal structure. Kao (2014a) reviews the related previous studies and indicates that the results from the network DEA are more significant and informative than those obtained from the conventional black-box approach, where the operations of the component processes are overlooked. Bian et al. (2016) apply the network DEA to analyze the parallel subsystems of China's economic system, which is composed of three internal parallel industries: primary, secondary, and tertiary. Therefore, network DEA is one of the best methods to investigate the efficiency of the internal economic systems. In addition, based on our limited knowledge, there is no evidence of any previous research applying the network DEA approach to study the efficiency of regional economic systems. This study would then be the first in this area to extend the application of the network DEA model. In addition, we also include the shared inputs and undesired variables at different stages in our model.

This study applies the network DEA model to investigate the efficiency of Taiwan's regional economic system during the period from 2003 to 2014. The regional economic system of Taiwan's counties/cities has been divided into five stages, namely, entrepreneurship, sustainability, operation, distribution, and consumption. The shared inputs and undesirable variables have been included in the analysis framework. Our findings indicate that the highest and lowest average efficiency scores are at the operation and sustainability stage in the economic systems in Taiwan's counties/cities, respectively. A gap exists between the average efficiency at the entrepreneurship and operation stage in the rural and urban groups and the mean in urban areas is higher than that seen in local areas. Besides, there are gaps between the service and non-service counties/cities at the all stages. Finally, our study indicates that regional differences persist during all the stages. The remaining part is organized as follows: in section 2, we review the existing body of literature on regional efficiency. Section 3 contains the analysis framework, including the network structure of economic systems of Taiwan's counties/cities and the model settings of the slack-based method (SBM) network DEA. Section 4 describes the variables selected in each stage, their processing methods, and the basic descriptive statistics; section 5 shows the empirical results of our model, and section 6 concludes with the final discussion.

II. Literature Review

The models used as measurement methods in regional efficiency studies are DEA-related with specific considerations. Occasionally, a few studies apply the stochastic frontier model for analyzing regional efficiency. Based on our current knowledge, we see that Zhang et al. (2015b) applied a dynamic stochastic frontier model to evaluate regional financial efficiency. Data envelopment analysis (DEA) related studies on regional efficiency treat the local administrative districts as decision-making units (DMUs) that can improve their economic performance through various administrative strategies. Thus, these studies use aggregated data. Chang et al. (1995) applies the conventional DEA and productivity analysis to analyze the efficiency of Taiwan's local government. Initially, most studies consider broad economic variables such as labor and capital as the inputs in their model and the local GDP/GNP as the output variables. The term for economic performance is called "regional efficiency." However, such studies are criticized for their ignorance of the influence of pollution variables under the concept of sustainable development. They are the byproducts of economic outputs and could result in negative influences on the environment of a region. Thus, studies in this field began to incorporate pollution variables into their analysis framework by treating them as undesirable outputs, such as the amount of CO_2 emissions. Accordingly, the term of economic performance was changed to "regional environmental efficiency." The DEA model with directional distance function incorporates undesirable outputs into the model associated with the explicit direction to expand outputs and contract inputs, and undesirable outputs as reference sets for gauging efficiency (Halkos and Tzeremes, 2011, 2013; Goto et al., 2014; Halkos et al. 2016). In addition, Yang et al. (2015) use the super-efficient DEA approach to differentiate some of the efficient regional administrative districts that have identical efficiency scores equal to 1 in the basic DEA models. Besides, Wang et al. (2013b) apply the DEA window analysis to compare the efficiency level, while considering the problem of a limited number of China’s local governments during a particular period. Finally, other researchers apply the total-factor efficiency approach while considering the inter-temporal efficiency changes of regions. Finally, Zha et al. (2016) apply the chance constrained DEA by considering multiple performance measures that are stochastic. Yang et al. (2017) also propose a bootstrapping approach in global DEA for solving the problem of applying the statistical inference on DEA scores. Such models are categorized as the radial approach in DEA analysis.

As for the efficiency analysis of Taiwan’s local governments, except Chang et al. (1995), Sie and Shiue (2010) evaluates the financial performance of 29 townships in Taipei County (now is New Taipei City) in Taiwan by conducting DEA and Slack Variable Analysis (SVA). Chang et al., (2002) apply the DEA to evaluate the operational efficiency in 23 prefectures in Taiwan with the consideration of factors influencing the operational efficiency. Wang and Zeng (2006) apply the DEA model to measuring the efficiency of utilizing financial resources of Taiwan’s local governments. Wu et al. (2010) apply the DEA and Free Disposal Hull (FDH) to evaluate the public expenditure efficiency of Taiwan’s local governments. Yao (2010) applies the stochastic frontier analysis to discuss the efficiency of Taiwan's local governments. Huang and Wang (2012) evaluate the multi-dimensional expenditure efficiency of Taiwan’s local governments using the DEA approach. Huang and Wang (2015) apply DEA to evaluate the expenditure efficiency of Taiwan’s counties and cities and then used the Tobit model to explore the impact of the overall allocation of taxes and subsidies on expenditure efficiency. Wang and Zheng (2017) apply the DEA model to measure the efficiency of developing own financial resources, and to explore its relationship associated with their local financial situation. Finally, Wu et al. (2018) apply DEA explore the fiscal performance of Taiwan’s local government. To sum up, in spite of the measurement of fiscal and expenditure efficiency, no previous studies focuses on the efficiency of economic system of Taiwan’s local government.

However, several recent studies adopted the alternative models in the DEA analysis approach, such as the non-radial directional distance function models, to estimate regional environmental efficiency (Ruiz-Fuensanta, 2016) and energy efficiency (Zhou et al., 2012; Wang et al., 2013a). Such models consider the slackness problems of inputs and outputs caused by the radial and angular choices (Song et al., 2013). Zhang and Choi (2013) measure the energy efficiency of China's regional economy by applying slacks-based measure. Analysis Zhang et al. (2015a) and Lin and Du (2013) consider the condition of group heterogeneity among regions by applying the meta-frontier slack-based approach. Yao et al. (2015) further consider an explicit direction to expand outputs and contract inputs and undesirable outputs by adopting regional heterogeneity, or the meta-frontier non-radial directional distance function model. Huang et al. (2014b) propose a new data envelopment analysis model by combining global benchmark technology, undesirable outputs, super efficiency, and slacks-based measure and called it the GB-US-SBM model. In addition, Wang et al. (2013a) apply the range-adjusted measure (RAM) DEA by normalizing input and output values through equalization factors for studies on China’s regions.

Finally, as for the studies considering the internal structure among different sectors on regional efficiency, also known as the multi-stage/network DEA, Wu et al. (2017) propose a new two-stage DEA model to evaluate the environmental efficiency of China’s economic system by considering undesired outputs. Similarly, Wu et al. (2016) provide an approach for analyzing the reuse of undesirable intermediate outputs in a two-stage production process with a shared resource of 30 provincial-level regions in China. The former proposes that the environmental system in a region is composed of industrial production subsystems and pollution treatment processes. The latter considers that the mode of a circular economy in a region contains the production stage and the disposal stage. Chen (2017) applies the multi-activity DEA model to analyze the departmental and overall regional performance in Taiwan’s local regions. Bian et al. (2016) examine the energy efficiency of the economic system in China by composing three internal parallel industries: primary, secondary, and tertiary, with a proposed parallel slacks-based measure approach. Chen (2014) applies the meta-DEA to investigate the heterogeneity of economic production technology between Taiwan's service-typed and nonservice-typed cities and counties to investigate their catch-up of economic production technology. Shan (2014) applies the cost stochastic frontier model to explain the relationship between the provision of a given output level and the public expenditure in local government.

To sum up, the DEA models have been widely applied to studies focusing on the performance of production or environmental systems in a region, and a few have conducted a joint evaluation of performance and productivity changes in different departments. However, very few studies applied the multi-activity/multi-stage network DEA in this field, such as Wu et al. (2016), Bian et al. (2016), and Chen (2017). Among them, Wu et al. (2016) and Chen (2017) incorporate the shared inputs and undesired outputs into the system. However, the internal structures in their proposed framework mostly relate to the production stage in economic subsystems and others only. Based on our limited knowledge, no previous study has analyzed regional economic performance from the administrative perspective of the whole system. Thus, in this study, we not only propose an internal structure from the perspective of the entire regional economic system but also divide this system into a series of five processes—entrepreneurship, sustainability, operation, distribution, and consumption—while considering the shared inputs and undesirable variables.

III. Methodology: SBM Network DEA

Network DEA models were introduced by Färe and Grosskopf (1996) and Färe and Grosskopf (2000). They investigated the so-called “black box” for the first time (Tone and Tsutsui, 2009). This model and its subsequent prototypes utilize the radial measure of efficiency, e.g., the CCR (Charnes et al., 1978) or the BCC (Banker et al., 1984) models as the basic DEA methodology and the production possibility set. The radial models are based on the assumption that inputs or outputs undergo proportional changes (Tone and Tsutsui, 2009). In order to explore the sources of inefficiency from individual sub-processes, the network DEA was proposed. Thus, the overall efficiency of a decision-making unit (DMU) is decomposed into multiple stages (Seiford and Zhu, 1999; Sexton and Lewis, 2003; Kao and Hwang, 2008) and developed into a network structure that solves the “black box” problem in conventional DEA (Prieto and Zofio, 2007; Mostafa, 2009; Yu, 2010; Chiu et al., 2014). In addition, Tone and Tsutsui (2009) introduce the Network SBM DEA model that uses the SBM approach, which was first introduced by Tone (2002) for evaluating efficiency. The SBM is a non-radial method and is suitable for measuring efficiencies when inputs and outputs may change non-proportionally by evaluating the deficit in output and excess utilization in input, which are the slacks used to assess efficiency. Through the evaluated slacks, we can also identify the inefficiency causing insufficient output or excess input (Huang et al., 2014a). Kao (2014a) reviews the related previous works of network DEA and compares their advantages and disadvantages. Lozano (2015) proposes an alternative model by considering the exogenous inputs and outputs at the system level instead of the process level. This model also relaxes the constraints for the links of intermediate variables between two stages, thus enhancing the discriminating power of the model.

A. Conceptual Framework of Economic System in Taiwan’s Counties/Cities

We propose a conceptual framework of economic system in Taiwan’s counties/cities in Figure 1. There are five stages in this system, including entrepreneurship, sustainability, operation, allocation, and consumption. We propose this system from the perspective of the department of economic affairs in the local government. Our concerns of this system are as follows:

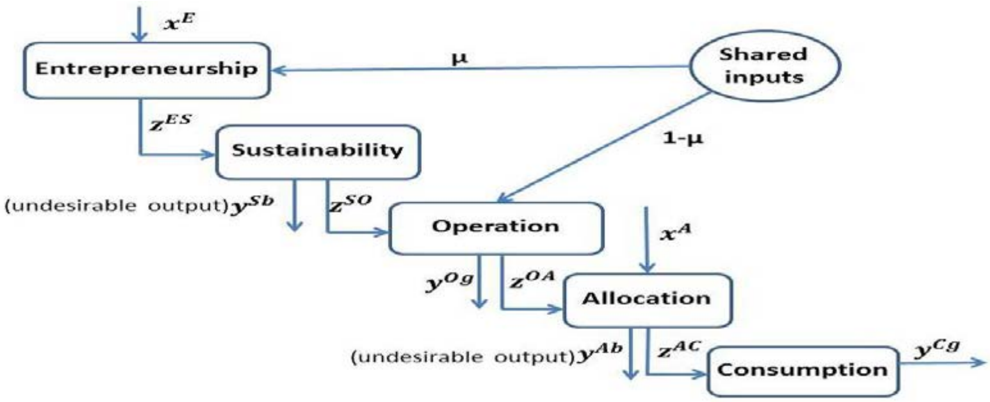

Figure 1 Conceptual framework of economic system in Taiwan's counties/cities

1. An officer in the department of economic affairs has the objective of attracting more investments, creating more employment, helping families to earn higher incomes, and offering a better living environment/standard for the inhabitants.
2. For the first two objectives, the system has to create an environment for entrepreneurs to not only start and develop their own businesses effortlessly for survival and sustainability, but to easily operate and create more production values. If managements in economic environments are more efficient, there will be more entrepreneurial activities, involving more investment, higher demand for labor, and thus generating more employment and production outputs. Therefore, we include entrepreneurship, sustainability, and operations in the system.
3. Next, for building a conducive economic environment, the official administration system should be able to convert the production values created by the firms/companies such as employees' salaries and profits for the owners of firms/companies, and other external payments such as property income and transfer receipts to the income levels of the local residents. We define such a converting mechanism as the allocation stage. Higher conversions in a local government improve economic administration.

4. Finally, after paying taxes from their income, citizens use the remainder to purchase necessities required for their daily living. In an economic environment in which residents with disposable income spend less money on consumption and save more than their counterparts, it would be considered that the economic administration of this local government is better compared to others. We define this as the consumption stage.

In Figure 1, x^E and x^A indicate the vectors of input variables at the entrepreneurship and allocation stage, respectively; y^{Og} and y^{Cg} are the vectors of stand-alone desirable outputs for the operation and consumption stages, respectively; z^{ES}, z^{SO}, z^{OA}, and z^{AC} are the vectors of intermediate variables, which are the desirable outputs of the previous stages and inputs for the next stage. Besides, y^{Sb} and y^{Ab} are the vectors of undesirable outputs for the sustainability and allocation stages, respectively. Finally, x_1^{sh} is the vector of shared inputs and μ and $1-\mu$ represent the distribution ratios in the entrepreneurship and operation stages, respectively.

As shown in Figure 1, we incorporate the shared inputs in our proposed conceptual framework. It has earlier been applied in the multi-activity network DEA model proposed by Beasley (1995), Färe et al. (1997), Yu (2008), and Chen (2017). Such inputs are jointly used in different departments or at different stages.

B. SBM Network DEA

a. Production Possibility Set

We suppose there are N counties/cities in Taiwan, $n = 1, 2, ..., N$ and denote the county/city under evaluation as DMU_0, the vector of its input variables measuring the efficiency at entrepreneurship stage as $x_g^E \in R_+^G$ ($g = 1, 2, ..., G$) and the vector of output variables at this stage but also the vector of input variables at sustainability stage as $z_k^{ES} \in R_+^K$ ($k = 1, 2, ..., K$). Additionally, the vector of shared inputs is denoted as $x_r^{sh} \in R_+^R$ ($r = 1, 2, ..., R$). We also indicate the intensity variable, λ_n^E, which represents the weights of the reference units as a benchmark for DMU_0, as assumed for the linear programming problem. While measuring the performance of the sustainability stage in DMU_0, we assume that the vector of desirable outputs at this stage and the vector of input variables at the sustainability stage is $z_i^{SO} \in R_+^I$ ($i = 1, 2, ..., I$), whereas the vector of undesirable outputs is $y_j^{Sb} \in R_+^J$ ($j = 1, 2, ..., J$), and the intensity variable is λ_n^{SU}. On considering the performance of the operation stage in DMU_0, we assume the vector of desirable outputs at this stage and the vector of input variables at the allocation stage as $z_h^{OA} \in R_+^H$ ($h = 1, 2, ..., H$), the vector of stand-alone desirable output as $y_m^{OG} \in R_+^M$ ($m = 1, 2, ..., M$), and the intensity variable is λ_n^O.

Furthermore, to measure the performance of the allocation stage in DMU_0, we assume the vector x_{un}^A ($u = 1, 2, ..., U$) as the stand-alone input, the vector of desirable outputs at this stage and also the vector of input variables at the consumption stage is $z_p^{AC} \in R_+^P$ ($p = 1, 2, ..., P$), the vector of undesirable outputs is $y_v^{Ab} \in R_+^V$ ($v = 1, 2, ..., V$), and the intensity variable is λ_n^A. To consider the performance of the consumption stage in DMU_0, we assume the vector of desirable outputs as $y_l^{Cg} \in R_+^L$ ($l = 1, 2, ..., L$), and the intensity variable as λ_n^C. Accordingly, we assume the overall network Production Possibility Set (PPS) under VRS as following:

$$T^{system}\Big\{(x_{gn}^E, x_{rn}^{sh}, z_{kn}^{ES}, z_{in}^{SO}, y_{jn}^{Sb}, z_{hn}^{OA}, y_{mn}^{Og}, x_{un}^A, z_{pn}^{AC}, y_{tn}^{Ab}, y_{\ln}^{Cg}):$$

$$\sum\nolimits_{n=1}^{N} \lambda_n^E x_{gn}^E \le x_g^E, g = 1, 2, ..., G, \sum\nolimits_{n=1}^{N} \lambda_n^E \mu x_{rn}^{sh} \le \mu x_r^{sh}, r = 1, 2, ..., R,$$

$$\sum\nolimits_{n=1}^{N} \lambda_n^E z_{kn}^{ES} \ge z_k^{ES}, k = 1, 2, ..., K, \sum\nolimits_{n=1}^{N} \lambda_n^{SU} z_{kn}^{ES} \le z_k^{ES}, k = 1, 2, ..., K,$$

(12)

$$\sum_{n=1}^{N}\lambda_n^{SU} z_{in}^{SO} \ge z_i^{SO}, i = 1, 2, ..., I, \sum_{n=1}^{N}\lambda_n^{SU} y_{jn}^{Sb} \le y_j^{Sb}, j = 1, 2, ..., J,$$

$$\sum_{n=1}^{N}\lambda_n^{O} z_{in}^{SO} \le z_i^{SO}, i = 1, 2, ..., I,$$

$$\sum_{n=1}^{N}\lambda_n^{O} (1-\mu) x_{rn}^{sh} \le (1-\mu) x_r^{sh}, r = 1, 2, ..., R,$$

$$\sum_{n=1}^{N}\lambda_n^{O} z_{hn}^{OA} \ge z_h^{OA}, h = 1, 2, ..., H, \sum_{n=1}^{N}\lambda_n^{O} y_{mn}^{Og} \ge y_m^{Og}, m = 1, 2, ..., M,$$

$$\sum_{n=1}^{N}\lambda_n^{A} x_{un}^{A} \le x_u^{A}, u = 1, 2, ..., U, \sum_{n=1}^{N}\lambda_n^{A} z_{hn}^{OA} \le z_h^{OA}, h = 1, 2, ..., H,$$

$$\sum_{n=1}^{N}\lambda_n^{A} z_{pn}^{AC} \ge z_p^{AC}, p = 1, 2, ..., P, \sum_{n=1}^{N}\lambda_n^{A} y_{vn}^{Ab} \le y_v^{Ab}, v = 1, 2, ..., V,$$

$$\sum_{n=1}^{N}\lambda_n^{C} z_{pn}^{AC} \le z_p^{AC}, p = 1, 2, ..., P, \sum_{n=1}^{N}\lambda_n^{C} y_{ln}^{Cg} \ge y_{ln}^{Cg}, l = 1, 2, ..., L,$$

$$\sum_{n=1}^{N}\lambda_n^{E} = 1, \sum_{n=1}^{N}\lambda_n^{SU} = 1, \sum_{n=1}^{N}\lambda_n^{O} = 1, \sum_{n=1}^{N}\lambda_n^{A} = 1, \sum_{n=1}^{N}\lambda_n^{C} = 1,$$

$$\sum_{n=1}^{N}\lambda_n^{SU} z_{in}^{SO} \ge z_i^{SO}, i = 1, 2, ..., I, \sum_{n=1}^{N}\lambda_n^{SU} z_{kn}^{ES} \ge z_k^{ES}, k = 1, 2, ..., K,$$

$$\sum_{n=1}^{N}\lambda_n^{E} = 1, \sum_{n=1}^{N}\lambda_n^{SU} = 1, \sum_{n=1}^{N}\lambda_n^{O} = 1, \sum_{n=1}^{N}\lambda_n^{A} = 1, \sum_{n=1}^{N}\lambda_n^{C} = 1,$$

$$\lambda_n^{E} \ge 0, \lambda_n^{SU} \ge 0, \lambda_n^{O} \ge 0, \lambda_n^{A} \ge 0, \lambda_n^{C} \ge 0, n = 1, 2, ..., N\} \quad (1)$$

We notice that the above model assumes the variable returns-to-scale (VRS). However, if we delete the constraint?? $\sum_{n=1}^{N}\lambda_n^{E} = 1, \sum_{n=1}^{N}\lambda_n^{SU} = 1, \sum_{n=1}^{N}\lambda_n^{O} = 1, \sum_{n=1}^{N}\lambda_n^{A} = 1,$ and $\sum_{n=1}^{N}\lambda_n^{C} = 1$, we can deal with the constant returns-to-scale (CRS) case as well. By setting the variable returns-to-scale (VRS), the production frontiers are spanned by the convex hull of the existing DMUs (Tone and Tsutsui, 2009), and thus the frontiers have concave characteristics (Cooper et al., 2007). In other words, VRS technology takes the scale of observed DMUs into account for measuring efficiency. Considering the scale gaps among Taiwan’s counties and cities, we adopt VRS technology in this study.

b. Efficiency Scores

In accordance with the assumption of network technology in (1), the proposed network DEA model for measuring the system (overall) efficiency of DMU_0 at time t on the lines of the concept mentioned in Kao (2014b) is as follows:

$$TE^{overall} = Min\frac{\beta}{\alpha}$$

Subject to:

$$\begin{aligned}
&\sum_{n=1}^{N}\lambda_n^E x_{gn}^E = x_g^E - s_g^{E-},\ g=1,2,...,G,\ \sum_{n=1}^{N}\lambda_n^E \mu x_{rn}^{sh} = \mu x_r^{sh} - s_r^{E,sh-},\ r=1,2,...,R,\\
&\sum_{n=1}^{N}\lambda_n^E z_{kn}^{ES} = z_k^{ES} + s_k^{ES+},\ k=1,2,...,K,\\
&\sum_{n=1}^{N}\lambda_n^{SU} z_{kn}^{ES} = z_k^{ES} - s_k^{ES-},\ k=1,2,...,K,\ \sum_{n=1}^{N}\lambda_n^{SU} z_{in}^{SO} = z_i^{SO} + s_i^{SO+}, i=1,2,...,I,\\
&\sum_{n=1}^{N}\lambda_n^{SU} y_{jn}^{Sb} = y_j^{Sb} - s_j^{Sb-},\ j=1,2,...,J,\ \sum_{n=1}^{N}\lambda_n^{O} z_{in}^{SO} = z_i^{SO} - s_i^{SO-}, i=1,2,...,I,\\
&\sum_{n=1}^{N}\lambda_n^{O}(1-\mu)x_{rn}^{sh} = (1-\mu)x_r^{sh} - s_r^{O,Sb-},\ r=1,2,...,R,\\
&\sum_{n=1}^{N}\lambda_n^{O} z_{hn}^{OA} = z_h^{OA} - s_h^{OA+}, h=1,2,...,H,\\
&\sum_{n=1}^{N}\lambda_n^{O} y_{mn}^{Og} = y_m^{Og} + s_m^{Og+}, m=1,2,...,M,\\
&\sum_{n=1}^{N}\lambda_n^{A} x_{un}^{A} = x_u^{A} - s_u^{A-},\ u=1,2,...,U,\ \sum_{n=1}^{N}\lambda_n^{A} z_{hn}^{OA} = z_h^{OA} - s_h^{OA-}, h=1,2,...,H,\\
&\sum_{n=1}^{N}\lambda_n^{A} z_{pn}^{AC} = z_p^{AC} - s_p^{AC-},\ p=1,2,...,P,\ \sum_{n=1}^{N}y_n^{A} z_{vn}^{Ab} = y_v^{Ab} - s_v^{Ab-}, v=1,2,...,V,\\
&\sum_{n=1}^{N}\lambda_n^{C} z_{pn}^{AC} = z_p^{AC} - s_p^{AC-},\ p=1,2,...,P,\ \sum_{n=1}^{N}\lambda_n^{C} y_{ln}^{Cg} = y_l^{Cg} + s_l^{Cg+},\ l=1,2,...,L,\\
&s_g^{E-}\ge 0,\ s_k^{ES+}\ge 0,\ s_k^{ES-}\ge 0,\ s_i^{SO+}\ge 0,\ s_j^{Sb-}\ge 0, s_i^{SO-}\ge 0,\ s_h^{CA+}\ge 0,\ s_m^{Og+}\ge 0,\\
&s_h^{CA-}\ge 0,\ s_u^{A-}\ge 0,\ s_p^{AC+}\ge 0,\ s_v^{Ab-}\ge 0,\ s_p^{AC-}\ge 0,\ s_l^{Cg+}\ge 0,\ s_r^{E,sh-}\ge 0,\ s_r^{O,sh-}\ge 0,\\
&\sum_{n=1}^{N}\lambda_n^{E} = 1, \sum_{n=1}^{N}\lambda_n^{SU} = 1, \sum_{n=1}^{N}\lambda_n^{O} = 1, \sum_{n=1}^{N}\lambda_n^{A} = 1, \sum_{n=1}^{N}\lambda_n^{C} = 1,\\
&\lambda_n^E \ge 0,\ \lambda_n^{SU}\ge 0,\ \lambda_n^{O}\ge 0,\ \lambda_n^{A}\ge 0,\ n=1,2,...,N\}
\end{aligned} \quad (2)$$

where

$$\beta = w_E\left(1-\left(\frac{1}{G+R}\right)(\sum_{g=1}^{G}s_g^{E-}/x_g^E+\sum_{g=1}^{G}s_r^{E,sh-}/\mu x_r^{sh})\right)+w_{SU}\left(1-\left(\frac{1}{K}\right)(\sum_{k=1}^{K}s_k^{ES-}/z_k^{ES})\right)$$

$$+w_O\left(1-\left(\frac{1}{I+R}\right)(\sum_{i=1}^{I}s_i^{SO-}/z_i^{SO}+\sum_{g=1}^{G}s_r^{O,sh-}/(1-\mu)x_r^{sh})\right)$$

$$+w_A\left(1-\left(\frac{1}{H+U}\right)(\sum_{h=1}^{H}s_h^{OA+}/z_h^{OA}+\sum_{u=1}^{U}s_u^{A-}/x_u^{A-})\right)+w_C\left(1-\left(\frac{1}{l}\right)(\sum_{p=1}^{p}s_p^{AC-}/z_p^{AC})\right),$$

and

$$\alpha = w_E\left(1+\left(\frac{1}{K}\right)\sum_{k=1}^{K}s_k^{ES+}/z_k^{ES}\right)+w_{SU}\left(1+\left(\frac{1}{I+J}\right)(\sum_{i=1}^{I}s_i^{SO+}/z_i^{SO}+\sum_{j=1}^{J}s_j^{Sb-}/y_j^{Sb})\right)$$

$$+w_O\left(1+\left(\frac{1}{H+M}\right)(\sum_{h=1}^{H}s_h^{OA+}/z_h^{OA}+\sum_{m=1}^{M}s_m^{Og+}/y_m^{Og})\right)$$

$$+w_A\left(1+\left(\frac{1}{P+V}\right)(\sum_{p=1}^{P}s_p^{AC+}/z_p^{AC}+\sum_{v=1}^{V}s_v^{Ab-}/y_v^{Ab})\right)+w_C\left(1-\left(\frac{1}{L}\right)\sum_{l=1}^{L}s_l^{Cg+}/y_{\ln}^{Cg}\right).$$

Additionally, $s_g^{E-}(g=1,2,...,G)$ and $s_k^{ES+}(k=1,2,...,K)$ are the vectors of slack variables for inputs, stand-alone outputs, and intermediate variables (outputs) at the entrepreneurship stage, respectively; s_k^{ES-} $(k=1,2,...,K)$, and s_i^{SO+} $(i=1,2,...,I)$ are denoted as vectors of slack variables for intermediate variables (inputs), intermediate variables (outputs), and undesirable outputs in the sustainability stage, respectively; s_i^{SO-} $(i=1,2,...,I)$, s_h^{OA+} $(h=1,2,...,H)$ and s_m^{Og+} $(m=1,2,...,M)$ represent the vector of slack variables for the intermediate variables (inputs), intermediate variables (outputs), and stand-alone outputs in the operation stage, respectively; s_u^{A-} $(u=1,2,...,U)$, s_h^{OA-} $(h=1,2,...,H)$, s_p^{AC+} $(p=1,2,...,P)$, s_v^{Ab-} $(v=1,2,...,V)$, are the vectors of slack variables for the stand-alone inputs, intermediate variables (inputs), intermediate variables (outputs), and undesirable outputs in the distribution stage, respectively; s_p^{AC-} $(p = 1, 2, ..., P)$ and s_l^{Cg+} $(l = 1, 2, ..., L)$ are the vectors of slack variables for the intermediate variables (inputs), intermediate variables (outputs), and undesirable outputs in the consumption stage, respectively; finally, $s_r^{E,sh-}$ $(r = 1, 2, ..., R)$ and $s_r^{O,sh-}$ $(r = 1, 2, ..., R)$ are denoted as the vectors of slack variables for shared inputs at the entrepreneurship and operation stage, respectively.

Therefore, the efficiency of the entrepreneurship stage is measured as:

$$TE^E = \frac{1 - \left(\frac{1}{G+R}\right)\left(\sum_{g=1}^{G} s_g^{E-} / x_g^E + \sum_{r=1}^{R} s_r^{E,sh-} / \mu x_r^{sh}\right)}{1 + \left(\frac{1}{K}\right)\sum_{k=1}^{K} s_k^{ES+} / z_k^{ES}}, \quad (3)$$

the efficiency of the sustainability stage is measured as:

$$TE^{SU} = \frac{1 - \left(\frac{1}{K}\right)\sum_{k=1}^{K} s_k^{ES-} / z_k^{ES}}{1 + \left(\frac{1}{I+J}\right)\left(\sum_{i=1}^{I} s_i^{SO+} / z_i^{SO} + \sum_{j=1}^{J} s_j^{Sb-} / y_j^{Sb}\right)}, \quad (4)$$

the efficiency of the operation stage is measured as:

$$TE^O = \frac{1 - \left(\frac{1}{I+R}\right)\left(\sum_{i=1}^{I} s_i^{SO-} / z_i^{SO} + \sum_{g=1}^{G} s_r^{E,sh-} / (1-\mu) x_r^{sh}\right)}{1 + \left(\frac{1}{H+M}\right)\left(\sum_{h=1}^{H} s_h^{OD+} / z_h^{OD} + \sum_{m=1}^{M} s_m^{Og+} / y_m^{Og}\right)}, \quad (5)$$

the efficiency of the allocation stage is measured as:

$$TE^{A}=\frac{1-\left(\frac{1}{H+U}\right)\left(\sum_{h=1}^{H}s_{h}^{OA+}/z_{h}^{OA}+\sum_{u=1}^{U}s_{u}^{A-}/x_{u}^{A-}\right)}{1+\left(\frac{1}{P+V}\right)\left(\sum_{p=1}^{P}s_{p}^{AC+}/z_{p}^{AC}+\sum_{v=1}^{V}s_{v}^{Ab-}/y_{v}^{Sb}\right)}, \tag{6}$$

and the efficiency of the consumption stage is measured as:

$$TE^{C}=\frac{1-\left(\frac{1}{I}\right)\sum_{p=1}^{P}s_{p}^{AC-}/z_{p}^{AC}}{1+\left(\frac{1}{L}\right)\left(\sum_{l=1}^{L}s_{l}^{Cg+}/y_{l}^{Cg}\right)} \tag{7}$$

c. The Link of Intermediate Variables

More importantly, the constraints of the intermediate products in the present study are different from that of Tone and Tsutsui (2009), but similar to Fukuyama and Mirdehghan (2012) and Kao (2014b). Tone and Tsutsui (2009) refer to two kinds of settings on the constraints of intermediate variables between the two stages they are involved in, namely, the free and fixed links. In the free link, the linking activities are freely determined (discretionary) while maintaining continuity between inputs and outputs, indicating that DMUs control the intermediate products. In the fixed link, the linking activities remain unchanged (non-discretionary), implying that the intermediate products are beyond the control of DMUs. However, Chen et al. (2013) indicate that the difference between these two links is minor. In addition, Fukuyama and Mirdehghan (2012) point out that these two links do not consider slacks of intermediate products while determining overall efficiency and divisional efficiency as both employ equality constraints on intermediate products and show the inappropriateness of such settings in identifying the efficiency status of DMUs and their divisions. To solve this problem, they proposed the inequality setting on the constraints of intermediate products by adding the slacks and including them into the subjective function. Kao (2014b) had adopted such settings. However, in this study, the discussion of different link settings is not out purpose.

Thus, to keep things simple and being focused, we adopted the link settings of Kao (2014b) .

d. Weights

According to Tone and Tsutsui (2009), weights for each division in (2) are pre-specified to represent their relative importance to the system. They must be positive and amount to 1 over all the divisions. The authors also defined the numerator and denominator (in reciprocal form) in (8)-(12) as input- and output-oriented efficiencies of each stage, respectively, and those of (7) as input- and output-oriented efficiencies of the system. Under these definitions, the input and output efficiencies of the system become the weighted arithmetic and weighted harmonic means of those of the processes, respectively (Kao, 2014b). However, Kao (2014b) posits that these weights do not have to be pre-specified, but can be derived from the observations subsequently; each DMU has different weights for similar divisions. Kao (2014b) defines these weights as the output-oriented efficiency score (in reciprocal form) of a stage in Tone and Tsutsui (2009) to the sum of those of all the stages. In this study, we assume that all the stages in the economic system in Taiwan's counties/cities are equally important to government officials. Thus, the weights for all the stages should be the same.

IV. Variable Selection and Data Processing

To evaluate the overall and divisional performances of the economic system in Taiwan's counties/cities, we use the data provided by the Directorate General of Budget, Accounting, and Statistics in Taiwan's Executive Yuan on the website "Inquiry System for Counties'/Cities' Important Indicators" (ISCII, in Chinese). We introduce the variables used for each division in this section. According to a pitfall described in Dyson et al. (2001), incorporating indices, ratios, or percentages into the input/output set is acceptable if all the inputs and outputs are of the same kind; the danger occurs when attempts are made to mix these with volume measures. Thus, all the variables in this study are volume measures. Golany and Roll (1989) suggested that n should be greater than 2 × (a + b) (n, a, and b are the number of DMUs, the number of input variables, and the number of output variables, respectively), whereas Banker et al. (1984), Friedman and Sinuany-Stern (1998) and Cooper et al. (2007) proposed that n should be greater than 3 × (a + b). Therefore, in this study, we strictly limit the total number of input and output variables to $(a + b) \leq n / 3$ in each division, including the shared inputs and undesirable variables. Finally, as the DMUs in this study are Taiwan's counties and cities, all the variables are aggregated data on the basis of county/city to ensure the internal causality of these indicators.

A. Variables for the Entrepreneurship Stage

In this stage, we employ the "number of workforce (in thousand)" as a stand-alone input and the "number of new companies registered" and the "number of self-employed individuals" (in thousand) to be the output variables. Both number of workforce and new companies registered are collected directly from ISCII website. As for the number of self-employed individuals (in thousand), it is calculated by multiplying the number of employment (in thousand) with the ratio of self-employed individuals (%). Number of new companies registered and self-employed individuals are both desirable outputs in this stage, and the input variables of the sustainability stage. Besides, we also employ part of the shared input, the yearly expenses for economic development (billion TWD), as another input variable (available on ISCII website).

We choose "number of workforce" as the input in this stage because we consider it to represent the pool of entrepreneurs. Working-age people could not only choose to join the job market or to start their own business or both, but also stay at home as well. Thus we take this variable as the source (input) of entrepreneurship. Accordingly, the "number of new companies registered" and the "number of self-employed individuals" are selected as the output variable. Thus, we assume that the "number of workforce" in two local areas is the same. However, "number of new companies registered" and "number of self-employed individuals" in one area are higher compared to the other, connoting that economic environment in this local area is more suitable for entrepreneurial activities because its workforce is more vigorous in business activities. Besides, this also reflects that cost of doing business are lower, ease of doing business such as the procedure for registering a new firm is simpler, and market opportunities are more optimistic.

B. Variables for the Sustainability Stage

As mentioned in section 4.1, the input variables in this stage are "number of new companies registered" and "self-employed individuals." For the desirable output variable, we employ "number of registered companies" and "total registered capital" (billion TWD). These two variables are also applied as input variables at the operation stage. In addition, we also employ the number of company dissolutions, revocations, and terminations (CDRT) as undesirable variables. All the variables are available on the ISCII website. The reason for employing "number of registered companies" and "total registered capital" as the output variable is intuitive. In fact, even if it is a new or an incumbent firm in the market, they have to struggle for survival during a certain period (a calendar year in this study). If they can survive/sustain this period, then they would be included as registered companies and their capital would be counted as registered capital. As a result, the more number of new firms that survive, the numbers for these two variables will be higher. On the contrary, if they cannot survive until the end of the calendar year, they would be counted into the number of company dissolutions, revocations, and terminations variable; hence, it is considered an undesirable output. By building a favorable economic environment for firms' sustainability in a local area, the environment can support more firms to survive until the end of the calendar year and this would result in less dissolutions. Thus, such a local area would be more efficient at the sustainability stage.

C. Variables for the Operation Stage

In this stage, the outcome of the sustainability stage, i.e., “total number of companies registered” and “total registered capital” are the inputs. We also employ a part of the shared input, the yearly expenses for economic development (billion TWD), as another input variable. For the output variables, we consider not only the total amount of “compensation of employees and entrepreneurial income” (CEEI in billion TWD) as the output at this stage and intermediate input at the allocation stage but also the “sales revenue paid for others” (billion TWD) and the “total number of employees” (in thousands) as the stand-alone desirable output in this stage. CEEI is calculated by multiplying “total current income,” which is the summation of compensation of employees, entrepreneurial income, property income, and transfer receipts, with the ratios of CEEI of total current income in each year. The amount of total current income is calculated be multiplying the average current income per household with the “number of households” (collected from ISCII website). The ratios of CEEI are collected from the statistics of “Sources of Current Receipts” in the “Survey of Family Income and Expenditure” from the Directorate General of Budget, Accounting and Statistics (DGBAS) of the Executive Yuan of Taiwan. As for the processing of “sales revenue paid to others,” it is calculated by deducting CEEI from the amount of “business sales.” Finally, “total number of employees” is calculated by subtracting the number of self-employed individuals at the entrepreneurship stage from the total number of employed.

D. Variables for the Allocation Stage

As mentioned in the previous stage, we take CEEI as the input variable at this stage. In addition, we also include the “property income and transfer receipts” (billion TWD) variable as the stand-alone input in this stage by subtracting CEEI from “total current income”. As for the output variable, we employ “total disposable income” (billion TWD) as the desirable output and “total taxation” (billion TWD) as the undesirable output; both the output variables are calculated by multiplying their average values per household (collected from ISCII website) and number of households.

E. Variables for the Consumption Stage

Finally, we adopt "total disposable income" as the input and "total savings" (billion TWD) as the input and the desirable output at this stage, respectively. Total savings is calculated by multiplying the average savings per households (available on ISCII website) and the number of households. Generally, after the households receive their disposable income, they prefer to cut down spending on their everyday consumption items and save more money for their future. Thus, at this stage, if the economic environment in a county/city is more efficient than others, its residents would spend less disposable income on their living expenditure and assign more toward savings. For this reason, we adopt "total savings" as the desirable output. However, we did not include "total consumption expenditure" as the output variable because the summation of this variable and total savings amounts to total disposable income. Thus, this linear dependency causes "cross-redundancy" satiation as identified by Lee and Choi (2010). They also show that the addition or deletion of a cross-redundant variable does not affect the efficiency estimates yielded by the CCR or BCC models. Thus, we maintain total savings in this study only for exempting "cross redundancy.

F. Basic Statistics for Variables

Table 1 shows the descriptive statistics for the variables used in this study. All the monetary variables were deflated by the yearly consumer price index (CPI) (2011 as the base year) offered by the Directorate General of Budget, Accounting and Statistics (DGBAS) of Taiwan's Executive Yuan. First, the average annual expenditure for economic development is TWD 6820.71 billion; the average number of workforce, self-employed, and employees are 542.84, 93.21, and 425.54 thousand, respectively. In other words, during the period of our research survey, the share of self-employment was about 17.97% of total employment in Taiwan, on an average. The average number of new companies registered in the research period is about 1,938.31, whereas the average number of company dissolutions, revocations, and terminations is 1,675.97, or about 86.47% of the average number of new companies registered. On average, number of companies registered and total registered capital are around 30,094 and TWD 932.70 billion, respectively. The average amount of business sales allocated toward compensation of employees and entrepreneurial income (CEEI) and paid for others are approximately TWD 304.11 and TWD 1,612.04 billion, respectively. The average amount of property income and transfer receipts is about TWD 139.87 billion. Finally, the average amount of total disposable income, total taxation, and total savings stood at TWD 350.71, TWD 78.18, and TWD 75.68 billion, respectively.

Table 2 shows the correlation coefficients among the variables applied in this study. We find that some correlation coefficients between two variables are very high. Conventional DEA requires discarding two highly correlated input or output variables from the assessment processes to increase the discrimination in DEA. However, Podinovski and Thanassoulis (2007) showed that omitting one of the two highly correlated inputs or outputs could lead to a dramatic change in efficiency measures. Dyson et al. (2001) further emphasizes that if two inputs (or outputs) are perfectly positively correlated, but are not multiples of each other, the results of the DEA assessment may show significant variation. However, the variables with high correlation coefficients for each other are not inputs or outputs at the same stage. Thus, the requirement of high correlation coefficients in conventional DEA is not applicable in this study.

Table 1 Basic Statistics for Variables

Variable	Obs	Mean	Std. Dev.	Min	Max	Symbol
Yearly expenses for economic development (million TWD)	240	6820.71	6813.91	823.89	41714.86	x_1^{sh}
Number of workforce (in thousand)	240	542.87	506.40	35	2006.00	x_1^{E}
Number of new companies registered	240	1938.31	2850.26	220	12818.00	z_1^{ES}
Number of self-employed (in thousand)	240	93.21	76.25	6.20	272.94	z_2^{ES}
Number of companies registered	240	30094	44246.15	4810	174584.00	z_1^{SO}
Total registered capital (billion TWD)	240	932.70	2044.55	3.80	10909.60	z_2^{SO}
Number of company dissolution, revocation and termination	240	1675.97	2740.77	9.00	17878.00	y_1^{Sb}
CEEI (billion TWD)	240	304.11	332.83	15.76	1223.92	z_1^{OA}
Sales paid for others(billion TWD)	240	1612.04	2564.54	10.93	12672.55	y_1^{Og}
Number of employed (in thousand)	240	425.54	411.06	25.60	1688.44	y_2^{Og}
Property income and transfer receipts (billion TWD)	240	139.87	154.20	6.54	589.56	x_1^{A}
Total disposable income (billion TWD)	240	350.71	380.35	17.04	1418.68	z_1^{AC}
Total taxation (billion TWD)	240	78.18	130.46	0.60	700.49	y_1^{Ab}
Total savings (billion TWD)	240	75.68	83.20	3.91	309.73	y_1^{Cg}

Table 2 Correlation Coefficients among Variables

Symbol	μx_1^{sh}	x_1^E	z_1^{ES}	z_2^{ES}	z_1^{SO}	z_2^{SO}	y_1^{Sb}	z_1^{OD}	y_1^{Og}	y_2^{Og}	x_1^A	z_1^{AC}	y_1^{Ab}	y_1^{Cg}
x_1^{sh}	1													
x_1^E	0.7775	1												
z_1^{ES}	0.7822	0.8582	1											
z_2^{ES}	0.7578	0.9628	0.7955	1										
z_1^{SO}	0.8108	0.8797	0.9855	0.8108	1									
z_2^{SO}	0.6700	0.5250	0.8230	0.4513	0.8401	1								
y_1^{Sb}	0.7130	0.7875	0.9176	0.7368	0.9267	0.7831	1							
z_1^{OD}	0.8182	0.9562	0.9473	0.8814	0.9698	0.7281	0.8772	1						
y_1^{Og}	0.7461	0.6807	0.9038	0.6148	0.9173	0.9689	0.8535	0.8429	1					
y_2^{Og}	0.7746	0.9987	0.8635	0.9480	0.8857	0.5351	0.7917	0.9627	0.6884	1				
x_1^A	0.8190	0.9538	0.9314	0.8709	0.9618	0.7267	0.8638	0.9970	0.8379	0.9616	1			
z_1^{AC}	0.8181	0.9610	0.9397	0.8859	0.9646	0.7174	0.8711	0.9995	0.8343	0.9674	0.9983	1		
y_1^{Ab}	0.7354	0.6274	0.8436	0.5445	0.8713	0.9565	0.7839	0.8015	0.9601	0.6384	0.8044	0.7949	1	
y_1^{Cg}	0.8349	0.9225	0.9284	0.8598	0.9594	0.7585	0.8753	0.9824	0.8653	0.9270	0.9783	0.9816	0.8302	1

V. Empirical Results

To calculate the optimal solutions for the SBM network DEA model proposed in section 3, we apply the CONOPT solver in the GAMS system (GAMS Development Corporation, 2015) to solve the non-linear programming problem. Before implementing the solver, we have to assign the initial values of μ and $(1-\mu)$ to the constraints of shared inputs in (2). In this study, we first assign the initial values according to the ratios of the number of self-employed and employees to the total employment number in each county/city for each year. As for the lower and upper bounds of μ and $(1-\mu)$, we adopt their minimum and maximum ratios in each year, respectively. Table 3 shows these ratios in each year. After the optimal values are achieved, the values of μ^* and $(1-\mu^*)$ are also determined. The last four columns in Table 3 show the average values at optimality in each year.

A. Efficiency Analysis

Figure 2 shows the average divisional and overall/system efficiency scores under VRS technology from 2003 to 2014. Among the divisional efficiencies, the average scores at the operation stage are the highest, while the average efficiency scores at the sustainability stage are always the lowest ones. There are three crests and two troughs in the research period. The crests are in year 2005, 2009, and 2013, and the troughs are in year 2008 and 2011, respectively. During the entire research period, the trend of efficiency scores at the sustainability stage is seen decreasing. In addition, the ranks of the average scores at the entrepreneurship, allocation, and consumption stages are unstable. However, after 2007, the average scores at the entrepreneurship and allocation stages are continuously higher than the scores at the consumption stage. Besides, the average efficiency scores of the overall (complete system) are relatively stable and are located between 0.749 (2011) and 0.800 (2005). The

Table 3 Minimum and Maximum of Initial Values and Mean of Optimal Values of μ and $1-\mu$

Year	**Upper and Lower Bound of Initial Values**				**Mean of Optimal Values**			
	μ		$1-\mu$		μ^*		$1-\mu^*$	
	Min.	**Max.**	**Min.**	**Max.**	**CRS**	**VRS**	**CRS**	**VRS**
2003	0.164	0.298	0.702	0.836	0.238	0.235	0.762	0.765
2004	0.160	0.287	0.713	0.840	0.238	0.227	0.762	0.773
2005	0.151	0.286	0.714	0.849	0.222	0.248	0.778	0.752
2006	0.141	0.286	0.714	0.859	0.237	0.226	0.763	0.774
2007	0.143	0.273	0.727	0.857	0.201	0.226	0.800	0.774
2008	0.147	0.261	0.739	0.853	0.244	0.243	0.756	0.758
2009	0.135	0.268	0.732	0.865	0.214	0.217	0.786	0.783
2010	0.127	0.279	0.721	0.873	0.227	0.230	0.773	0.770
2011	0.122	0.284	0.716	0.878	0.214	0.210	0.786	0.790
2012	0.117	0.263	0.737	0.883	0.190	0.183	0.810	0.817
2013	0.119	0.252	0.748	0.881	0.202	0.192	0.798	0.808
2014	0.124	0.252	0.748	0.876	0.216	0.204	0.784	0.796

values of the efficiency score also indicate that the entire system is still far away from the optimum efficiency level, even though they began to rise after 2011. Thus, the overall ranks among the average divisional efficiency scores of stages under VRS Technology are as follows: operation, allocation, consumption, and sustainability.

Furthermore, the average efficiency scores at the sustainability stage are always lower, and the ones in the other four stages are higher compared to those of the entire system. Hence, the main reason causing inefficiency of the entire system is ineffectiveness at the sustainability stage. Efficiency scores at the operation stage are higher compared to those at the entrepreneurship and sustainability stages; and scores at the entrepreneurship stage are always higher than those at the sustainability stage. This indicates that the economic environment in

Taiwan's counties/cities is more efficient for starting new firms and for operating firms that experienced the period of sustainability. In Taiwan, people believe in saying "better be the head of a dog than the tail of a lion". The Taiwanese entrepreneurial spirit drives business activities and a versatile economy. As a result, high efficiency is expected at the entrepreneurship stage. In addition, most of the firms registered in Taiwan are small- and medium-enterprises (SMEs), accounting for nearly 97.69% of total enterprises in Taiwan in 2015 (Small and Medium Enterprise Administration, 2015a). Especially, 99.79% of the new start-ups are SMEs (Small and Medium Enterprise Administration, 2015b). A characteristic feature of SMEs is operational flexibility, as responding to the demand trends and market changes must be done quickly and efficiently (Wadhwa, 2012). Thus, they can perform better at the operation stage as long as they survive the sustainability stage. However, the survival rate of SME startups is considered low in Taiwan (Executive Yuan, 2015). We do not have the exact figure for the survival rate. Thus, average efficiency scores at the sustainability stage in Taiwan are lower, compared to the operation and entrepreneurship stages. Finally, the above-mentioned information indicates that for officials responsible for economic affairs in

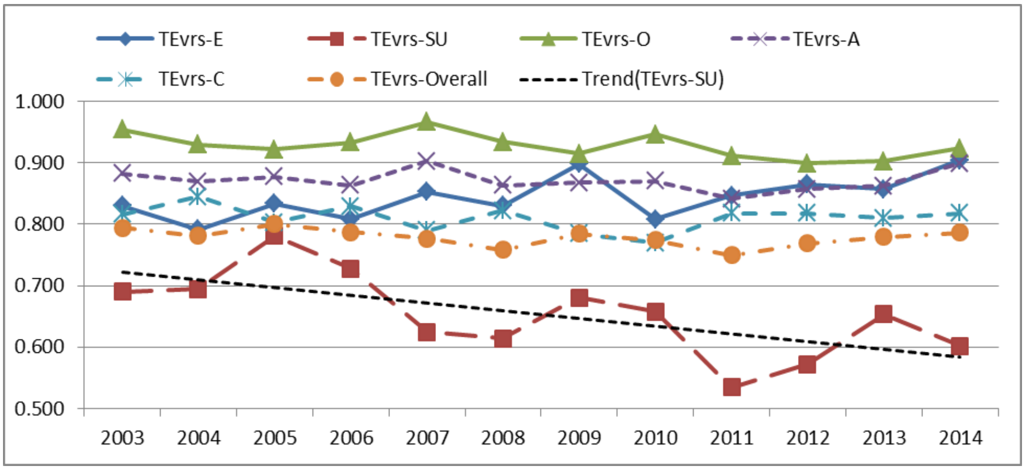

Figure 2　Average Efficiency Scores under VRS Technology from 2003 to 2014

Taiwan’s local government, the policies that help start-ups to overcome the period of sustainability would be the first priority of their administration.

Besides, as compared to the average efficiency scores at the allocation and consumption stages, the former are always higher than the latter. This implies that although the mechanism of changing CEEI and property income and transfer receipts into disposable income is more efficient, the average living costs in Taiwan’s counties/cities are not low, resulting in lower average efficiency scores. Officials of economic affairs should monitor the market situation and track the unusual rise in prices, or the structural change in industries.

In addition, we also know the slacks of each unlinked variables in each stage in local economic system. Table 4 shows the average values of each variables for each county/city. Firstly, we find that there is no slacks for variables in Taipei City and Penghu County. In other words, the local economic systems in these two places are the most efficient among Taiwan’s counties and cities. Secondly, we can find that the workforce in Hsinchu County is used insufficiently enough because its average slacks is the highest in this variable. As for Miaoli County, the average number of company dissolution, revocation and termination is much higher than others, which means that the firms in it are not easy to sustain. Thus county also has the highest average slack for sales paid for others. As for the number of employed (in thousand) and total taxation, we find that the average slacks in Keelung City are the highest, which means that the employees in Keelung City are not used sufficiently and the tax burden is higher than frontier county/city. Besides, the Taichung City has the highest average slack of total saving, which means that the saving level is still far from the frontier. Finally, we find that the slacks are widespread in total taxation and total savings among Taiwan’s counties and cities.

Table 4 The Average Slacks between 2003~2014

County/City	Number of workforce (in thousand)	Number of company dissolution, revocation and termination	Sales paid for others (billion TWD)	Number of employed (in thousand)	Total taxation (billion TWD)	Total savings (billion TWD)
New Taipei City	--	--	--	--	--	16.20
Taoyuan City	78.99	6.42	0.00	0.00	20.08	20.40
Taichung City	--	--	--	--	13.42	53.12
Tainan City	--	--	--	--	0.39	24.73
Kaohsiung City	--	--	--	--	37.88	3.15
Yilan County	28.67	--	12.87	3.62	3.15	10.00
Hsinchu County	94.49	--	142.78	17.06	4.11	11.60
Miaoli County	51.17	62.92	358.78	5.81	8.75	6.35
Changhua County	--	--	--	--	0.42	9.89
Nantou County	7.34	26.87	32.89	3.69	0.00	9.29
Yunlin County	--	--	--	--	29.49	3.13
Chiayi County	--	--	--	--	--	11.16
Pintung County	--	--	--	--	2.13	6.09
Taitung County	--	--	--	--	0.02	0.27
Hualien County	16.50	8.99	141.86	11.74	3.78	4.38
Keelung City	47.98	7.23	75.73	19.45	46.16	13.37
Hsinchu City	16.60	--	--	--	11.77	14.06
Chiayi City	6.06	--	--	--	1.56	4.78

In addition, we investigate the final ranking of counties/cities by summing up the number of times each one was ranked first at every stage and in the system. The results and the ranks are listed in the last two columns in Table 5. Not surprisingly, Penghu County emerged as the most efficient among all counties/cities in Taiwan. Taipei City, Kaohsiung City, and Taitung County were ranked second, third, and fourth, respectively. Among them, the economy scales of Penghu and Taitung Counties are the lowest in Taiwan. However, Taipei and Kaohsiung Cities are the most developed cities located in northern and southern Taiwan, respectively. They are also two of the three cities, including New Taipei City, with the biggest economy scales in Taiwan. The ranking indicates that the first four efficient counties/cities in Taiwan are at the extreme opposite in size, implying that to be an efficient economic system the size of a county/city should be either small or large enough. The last four efficient counties/cities are Keelung City, Miaoli County, Yilan County, and Nantou County.

Table 5 also offers a reference for Taiwan’s central government on decisions relating to subsidizing projects proposed by local governments for their economic development because the Table indicates the advantage and disadvantage stages of each local government. If the proposed project relates to efficiency improvement of the disadvantageous stage of a specific local government, it is reasonable for the central government to support such a project and subsidize the related expenditure. Otherwise, the central government should decline such proposals. Moreover, it is incumbent upon the local governments to prepare their projects that relate to improvement of their disadvantages in such a way that they earn the support of the central government.

Table 5 Capturing the Number of Times a County/City was Ranked First in Efficiency Scores under VRS (2003~2014)

County/City	Area	TEvrs-E	TEvrs-SU	TEvrs-O	TEvrs-A	TEvrs-C	TEvrs-Overall	Total	Rank
New Taipei City	North	12	6	12	0	1	0	31	8
Taipei City	North	12	12	12	0	12	3	51	2
Taoyuan City	North	6	0	12	0	2	0	20	11
Taichung City	Middle	12	1	3	0	0	0	16	14
Tainan City	South	6	3	12	0	0	0	21	10
Kaohsiung City	South	11	12	12	0	8	3	46	3
Yilan County	North	1	0	6	0	0	0	7	18
Hsinchu County	North	1	4	6	0	1	0	12	15
Miaoli County	Middle	0	5	2	0	0	0	7	19
Changhua County	Middle	12	6	12	2	2	0	34	5
Nantou County	Middle	4	0	6	0	0	0	10	17
Yunlin County	Middle	12	3	12	1	4	0	32	7
Chiayi County	South	12	1	10	10	0	0	33	6
Pintung County	South	3	0	12	0	1	0	16	13
Taitung County	East	8	7	12	6	8	3	44	4
Hualien County	East	0	8	1	0	2	0	11	16
Penghu County	South	12	12	12	12	12	12	72	1
Keelung City	North	1	1	3	0	0	0	5	20
Hsinchu City	North	5	12	12	0	0	0	29	9
Chiayi City	South	7	0	11	0	0	0	18	12

B. The Testing of Regional Gap

We also investigate whether an urban–rural gap exists between the efficiency scores by testing the significance of the differences in their group means. Then the t-test was implemented to investigate the significance of the difference between the group means. Table 6 lists the test results. We find that there is an urban–rural divide at the entrepreneurship and operation stage under VRS technology. The signs of the mean differences are positive, indicating that these two stages in urban areas are more efficient than the rural ones. The gaps here indicate that the economic environment in the cities could be more conducive to entrepreneurial and operational activities than in the counties. In contrast, the signs of the mean differences at the allocation and consumption stage are negative. Especially, the negative gap at the consumption stage indicates that life in the rural areas could be easier than life in the urban areas. Finally, from the perspective of the system, the mean difference is significantly positive. This means that the economic systems in urban areas are more efficient than the rural ones.

Table 6 Mean Comparison of TE Scores between Counties/Cities

Scores	County (A)			City (B)			Mean Difference (B-A)				Sig.
	Obs.	Mean	Std. Err.	Obs.	Mean	Std. Err.	Value	Std. Err.	t-value	Pr(t-value)	
TEvrs-E	132	0.797	0.019	108	0.900	0.016	0.103	0.026	3.980	0.0001	**
TEvrs-SU	132	0.626	0.026	108	0.684	0.028	0.058	0.038	1.507	0.1331	--
TEvrs-O	132	0.906	0.013	108	0.954	0.011	0.048	0.018	2.690	0.0076	**
TEvrs-A	132	0.883	0.010	108	0.856	0.013	–0.026	0.016	–1.621	0.1063	--
TEvrs-C	132	0.818	0.013	108	0.799	0.015	–0.018	0.020	–0.940	0.3479	--
TEvrs-Overall	132	0.760	0.012	108	0.800	0.013	0.040	0.018	2.234	0.0264	**

Note: ** represents 95% significance level.

We also compare the differences in the means between the service- and non-service-types of counties and cities. To test this difference in the means, we categorize the counties/cities as service- or non-service type by sorting them on the proportion of employment in the service sector. We use the average proportion of all counties/cities in the analysis period as the threshold value. A county/city with a higher proportion of employment in the service sector than this threshold value is categorized as a service-type county/city. Otherwise, it is regarded as a non-service-type county/city. We list the test results in Table 7.

This shows that there are significant gaps between Taiwan's service/non-service counties/cities at the sustainability, operation, distribution, and consumption stages and in the system under VRS. First, the positive sign at the sustainability stage indicates that new firms find it easier to go through this stage in the service areas. Similarly, the positive sign at the consumption stage implies that life in service areas is easier than that in non-service groups. Second, the negative sign of gap at the operation stage implies that the operations of firms located in the areas of the service group are more difficult than in the non-service areas. This could result from the fact that competition is higher in service-type areas. As for the negative sign at the allocation stage, it indicates that the economic environments of areas in the non-service group are more efficient than the ones in the service group. Finally, from the perspective of the whole system, the mean efficient score of the service group is significantly higher than the non-service group. This implies that the entire economic system for areas in the service group is more efficient than for those in the non-service group. In addition, such higher efficiency resulted from the domination of the positive gaps at the sustainability and consumption stages over the negative gaps at the operation and distribution stages. The policy implication here is that counties/cities that belong to the service group should improve their economic environments at the operation and distribution stages, and those that belong to the non-service group should improve their economic environments at the sustainability and consumption stages.

Table 7 Mean Comparison of TE Scores between Service/Non-service Counties/Cities

Scores	Non-service (A)			Service (B)			Mean Difference (B-A)				Sig.
	Obs.	Mean	Std. Err.	Obs.	Mean	Std. Err.	Value	Std. Err.	t-value	Pr(t-value)	
TEvrs-E	156	0.834	0.016	84	0.861	0.022	0.027	0.028	0.961	0.3374	--
TEvrs-SU	156	0.590	0.022	84	0.767	0.033	0.177	0.038	4.547	0.0000	**
TEvrs-O	156	0.940	0.010	84	0.905	0.019	–0.035	0.019	–1.858	0.0644	*
TEvrs-A	156	0.882	0.010	84	0.850	0.014	–0.038	0.017	–1.899	0.0588	*
TEvrs-C	156	0.788	0.012	84	0.850	0.018	0.061	0.021	2.963	0.0034	**
TEvrs-Overall	156	0.760	0.010	84	0.812	0.019	0.052	0.019	2.798	0.0056	**

Note: * represents 90% significance level; ** represents 95% significance level.

Finally, we test the effects of location on the average efficiency scores in Taiwan’s counties and cities. The “Strategic Plan for National Spatial Development”, proposed by the National Development Council in Taiwan’s Executive Yuan in 2010 divides Taiwan’s counties/cities into north, central, south, and east regions. We categorize our counties/cities according to this definition and test for differences in the TE scores among the regions using an ANOVA analysis. Table 8 lists the test results (the test results under CRS are listed in Table A10). The results show that there are differences among the mean efficiency scores between the regions in Taiwan, from the perspective of both the division and the entire system. We also find that the mean efficiency scores for the counties/cities located in the east are always higher than the other areas at the sustainability and consumption stages and always lower than the other areas at the entrepreneurship and allocation stages. However, the mean efficiency scores for counties/cities located in the southern area are always higher than the other areas at the entrepreneurship and operation stage and always lower than the other areas at the sustainability stage. As for the mean efficiency scores of the northern area, it is always higher than other areas at the allocation stage, but always lower than the other areas at the operation and consumption stages. Finally, there is no significant difference on the mean efficiency scores of the entire economic system among all the areas. From the test results, it is observed that counties/cities in eastern Taiwan should improve their efficiency at the entrepreneurship stage, while those located in northern Taiwan need to improve their efficiencies at the operation and consumption stages, and counties/cities in southern Taiwan should improve their efficiencies at the sustainability stage.

To sum up, the testing results from Table 6~8 indicated that the advantages and the disadvantages of different groups and areas. Thus, for the policy instrument should be implemented to improve the efficiency of all local economic system, there is no unique one could be applied for all. The policy instrument should be proposed and implemented based on the real situation of local economic system. Now that the advantages and the disadvantages are different among different groups and areas, the specific policy instruments for specific area or group are needed.

Table 8 ANOVA of TE Scores among the Regions

Scores	F-Value (d.f.=3, 236)	Pr (F-Value)	Sig.	Note#
TEvrs-E	4.75	0.0031	**	South > Middle > North > East
TEvrs-SU	5.27	0.0016	**	East > North > Middle > South
TEvrs-O	14.60	0.0000	**	South >East > Middle > North
TEvrs-A	36.95	0.0000	**	North > Middle >South > East
TEvrs-C	6.63	0.0003	**	East > South > Middle > North
TEvrs-Overall	0.71	0.5492	--	--

Note: ** represents 95% significance level; d.f. denotes degrees of freedom; # denotes the relationships between any two areas.

VI. Discussion and Conclusions

In this study, we apply the SBM network DEA to calculate the divisional and system efficiency scores of the proposed economic system of Taiwan's counties/cities using data for the period from 2003 to 2014. This method helps to avoid categorizing or treating an economic sector as a "black box" in the conventional DEA model. After calculating the divisional and systematic efficiency scores for the economic system in Taiwan's counties/cities, we also investigate the implications on the gaps of mean scores between the urban/rural areas and the service/non-service groups and among the regions.

Our first contribution is to apply the SBM network DEA model to analyze the regional efficiencies of the economic system. This is different from the study by Chen (2017), which applies the multi-activity network DEA to analyze the regional efficiencies of different parallel departments. In addition, our method and study interests are different from the conventional analyses on regional studies. Not many studies have investigated the inner structure of the economic sector or proposed a transmission structure among the economic variables. In other words, we extend the application scope of network DEA to the study of regional efficiency. This is the first one to apply the framework of SBM network DEA model to study the economic system with the integration of shared inputs and undesired variables.

Our second contribution is to examine the divisional and systematic efficiencies in an economic system for a given period of time. Local governments can also evaluate their own advantages and disadvantages from the results obtained by our analysis framework. Based on the above discussion, we show that the average efficiency scores are the highest at the operation stage and the lowest are at the sustainability stage for the period from 2003 to 2014. Besides, the average efficiency scores at the operation stage are always higher than the entrepreneurship and sustainability stages. Such results indicate that the economic environment in Taiwan's counties/cities is conducive to entrepreneurial and operation activities, but not very efficient for the survival of startups. In addition, the lower average efficiency scores at the consumption stage than the allocation stage indicate that people in Taiwan are unable to save money and spend most of their disposable income on consumption. Finally, we find that the top four efficient counties/cities in Taiwan in the period from 2003 to 2014 are Penghu County (south), Taipei City (north), Kaohsiung City (south), and Taitung County (east), and the last four efficient counties/cities are Keelung City (north), Miaoli County (central region), Yilan County(north), and Nantou County(central region).

We also find that an urban–rural gap exists in Taiwan's counties/cities at the entrepreneurial and operation stage during the period 2003–2014, indicating that the rural areas have advantages on entrepreneurial and operational activities. The higher efficiency of the economic systems in urban areas results from higher efficiency during these two stages. Furthermore, we also observe that the mean efficiency scores at the sustainability and consumption stage are significantly higher in the service group. Conversely, the non-service group is more efficient than the service group at the operation and allocation stage. The higher efficiency of the economic systems has resulted due to domination by the positive gaps at the sustainability and consumption stages over the negative gaps at the operation and distribution stage. Finally, we also find that there are locational effects on the average efficiency scores in Taiwan's counties and cities at each division, but not the whole system. We also find that the mean efficiency scores for counties/cities located in the eastern area are always higher at the sustainability and consumption stage, while those in the south are always higher at the entrepreneurial and operation stage and those in the north are always higher than the other areas in the allocation stage, respectively.

Our third contribution is to offer policy suggestions for officials responsible for managing economic affairs in different local governments to improve their efficiency in the economic system. In other words, the policies and suggestions based on our research framework may be more detailed and precise for stages in the economic system. As mentioned above, previous studies treat the economic sector as a "black box," from the perspective of both a country and a region, even though they indicate the importance of reviewing their efficiencies. Investigations into the internal structure of the economic system offer us more evidence on the regional economic developments that are not always manifest in the analysis framework in conventional DEA. For example, from the results listed in Table 4, we recommend to officials in charge of economic affairs in Keelung City (north), Miaoli County (central region), Yilan County (north), and Nantou County (central region) to promote policies that can improve efficiencies during all the stages. As for those in Taoyuan City (north) and Tainan City (south), they are to promote policies that can improve efficiencies at the entrepreneurial, sustainability, allocation, and consumption stages. Thus, they can reduce the potential for adopting general measures or the wrong policies. Based on our empirical results, the mean efficiency scores at the operation stage are higher, compared to those at the entrepreneurship and sustainability stages, indicating that Taiwan's local governments should adopt strategies to stimulate more entrepreneurial activities and improve the economic environment to augment the prospect of survival of new startups instead of offering policies to improve firms' operations. Besides, the lower average efficiency scores at the consumption stage also imply that the local government should factor in the economic mechanisms involved at this stage, such as lowering the overall living expenditure.

Finally, this study does not explore the analysis of productivity in either the divisions or the whole system. Future studies can explore this aspect by applying the proposed analysis framework provided in this study. Secondly, this study only analyzes the performance of the economic system in a county/city. Future studies can extend the analysis framework to include more subsystems in the administration of local governments by applying the concept of a multi-activity DEA model. Furthermore, we did not implement any econometric model to analyze the impact of efficiency of regional economic system by including some specific policy variables or regional policy instruments. This is because the purpose of this study is to propose an analysis framework of network EDA to analyze the local regional economic system. Thus, in the future study, it is pretty good to apply the calculated efficiency values in this study to understand the effects of regional policy instruments by construct the dynamic panel data model to directly offer the statistical evidence for the policy suggestion of efficiency enhancement. Finally, the SBM network DEA model is a static one. It does not mention the dynamic activities that already exist in the economic system. For example, the number of self-employed individuals in a county/city could influence this number in the subsequent years because of the demonstration effect of the level of efficiency at the entrepreneurship stage in the present year. Thus, for future studies, the system dynamics could be an alternate research direction.

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應用差額衡量之網絡資料包絡法衡量台灣各縣市地區經濟體系之效率

陳志成 *

摘　要

本研究應用差額衡量之網絡資料包絡法衡量 2003~2014 年間台灣各縣市經濟體系之效率；將各縣市的地區性經濟體系分爲五個階段：創業、存活、營運、分配、及消費等；研究結果顯示，在 2003~2014 年間各縣市的地區經濟體系的平均效率以營運階段爲最高，消費階段爲最低；其次城鄉縣市在創業與營運階段都有顯著的差異；服務業與非服務業縣市在存活、營運、分配與消費等階段存在顯著差異；最後，從台灣東、西、南、北四個區域來看，則各個區域在不同的階段有其擅長之處；各縣市主管經濟發展的官員可發現該縣市的優勢與劣勢階段，並據此作爲優先施政的選項，改善其整體經濟體系的表現。

關鍵詞：地區性效率、經濟體系、差額衡量法、網絡資料包絡法

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