Using Data Envelopment Analysis to Measure the Achievement and Change of Regional Development in Taiwan

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The purpose of this paper is to extend the use of the data envelopment analysis (DEA) approach, developed by Charnes, Cooper and Rhodes, and which proposes a mathematical programming model for measuring the relative effectiveness of an organization, which is used in evaluating the relative achievement of regional developments in 23 administrative regions of Taiwan in 1990. At the same time, this paper also extends the model for measuring the relative effectiveness of an organization to become a model for measuring the effectiveness change of an organization by merging it with the Malmquist productivity approach, as expressed by Färe *et al.* (1985, *The Measurement of Efficiency.* Boston: Kluwer-Nijhoff), and uses the model to determine whether the relative change of the regional development of the 23 administrative regions in Taiwan moved forwards or backwards between 1983 and 1990. The model in this paper can be used to measure the relative effectiveness and relative effectiveness change of an organization under multiple criteria, wherein each criterion represents a familiar performance ratio. The case in this paper also can provide useful information for the formulation of a regional development plan of Taiwan.

Keywords: data envelopment analysis, regional development, efficiency, effectiveness, effectiveness change.

1. Introduction

The ultimate objective of economic development is to increase the welfare of a nation's citizens, and improve the living environment. Since human activities are closely related to the development of industries, and deeply affected by regional development, the ways to measure the conditions of regional development are absolutely an essential subject in the establishment of a nation's public policies.

Over the past four decades of rapid development of the Taiwan area, the economy has grown at an annual average of 8·9%; this real rate of growth, which encompasses the total increased production of goods and heightened value of labour, indicates that production today amounts to 17 times what it was 40 years ago. At this time of steady

economic advancement and rapid increasing affluence, however, the nation is faced with a number of problems. The most serious of these are economic imbalance and a loss of social order, a failure of infrastructural construction to keep pace with rapid economic development, and a general deterioration of the living environment.

Although the economy has maintained a high level of prosperity and society has become more affluent day by day, the inability of infrastructural construction to keep pace with economic development in recent years has given rise to the emergence of economic imbalances and disorders one after the other, especially traffic congestion, environmental pollution, inferior residential quality, noise, litter, uncertain drinking water safety and deteriorating public security, as well as inadequate cultural and recreational facilities and a decline of the traditional Chinese ethic. All of these problems indicate that the R.O.C. in Taiwan is faced with a developmental bottleneck: "poverty in the midst of affluence".

The Republic of China in Taiwan is now going through a stage of socio–economic transition. As an advisory agency, the Council of Economic Planning and Development (CEPD) of the Executive Yuan is responsible for the design, review, co-ordination and evaluation of the nation's economic development. To solve thoroughly the problems of economic imbalance and social disorder mentioned above, and to accelerate the modernization of the country, the council placed the goals of "pursuing balanced regional development" and "improving the quality of life" among the top priorities of the policies involving the formulation of the Six-year National Development Plan started in 1989. The council hopes to strengthen infrastructural construction in slower development regions, solidify facilities in transportation and communications systems, housing, schools, cultural establishment, medical care, and reduce the development differences among different regions.

The implementation of balanced regional development requires a tremendous amount of money. The resources have to be used effectively. If the relative conditions of the regional development of each region can be learned in advance, useful information can be provided for the formulation of a balanced regional development plan. While formulating the regional development plans, the CEPD collects such indices of urban and regional development as population density, urban planned area as percentage of the total area, piped water supply of population served, number of local telephone subscribers per 100 people, number of physicians per 10 000 people, number of copies of newspapers and magazines sold per 1000 people, the average income per capita, and so on (Council for Planning and Development, 1990). These indicators covering the aspects of population, public utilities, transportation and communication, public health, education and culture, and regional economy help the CEPD to understand the current conditions of the development in each region.

Nevertheless, the various indicators of each region often fail to point to the same direction. For example, for a certain region, one indicator may be high, but another indicator may be very low. Therefore, it is necessary to add weight on the various indicators to obtain a compositive indicator for further understanding of the current conditions of the regional development of each region. The major problem, then, is how the various indicators should be weighted. An arbitrary attribution of weight usually ends up as a victim of subjectivity.

This paper extends the uses of DEA approach developed by Charnes et al. (1978), and simplifies the multiple performance indicators into a compositive indicator to measure the current achievement of the regional development in all county and urban regions of Taiwan. At the same time, the paper proposes a model for measuring the
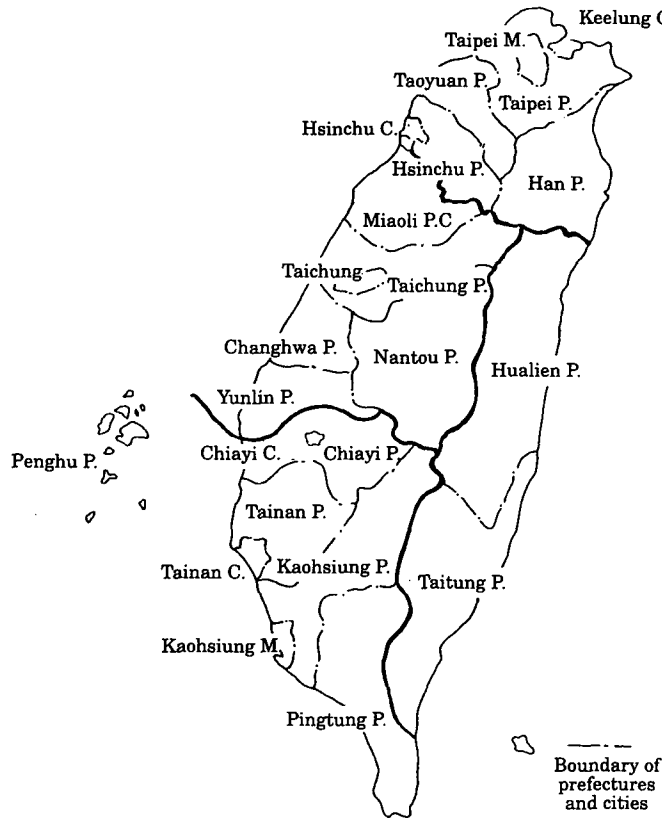
Figure 1. Jurisdiction of Taiwan area.

effectiveness change by combining the DEA approach with the Malmquist productivity approach expressed by Färe *et al.* (1992). This model is applied to evaluate the change of the regional development of the Taiwan area, and also serve as a basis to determine the priorities of all county and urban regions in the Taiwan area for regional development.

2. The problem

As shown in Figure 1, the Taiwan area is divided into 23 administrative regions, including the two municipalities under the direct jurisdiction of the Executive Yuan, Taipei and Kaohsiung, the five cities of Keelong, Hsinchu, Taichung, Tainan and Chiai under the jurisdiction of the provincial government of Taiwan Province, and the remaining 16 counties. As soon as the cabinet led by premier Hao Po-tsuen assumed office in June 1989, Hao ordered the CEPD to formulate the Six-year National Development Plan. For the formulation of the Six-year National Development Plan, the various ministries and agencies of central governments, Taiwan Provincial government, Taipei and Kaohsiung municipal government all presented their proposals; then, in accordance with the goals listed above and in consideration of the supply of national resources available, the CEPD brought together and arranged the different proposals into an integrated plan. During the execution of the plan, review and modifications will be made annually.

After working for 6 months, the council finished the proposal for the Six-year National Development Plan in January 1990. It listed a budget of NT$8·2 trillion, hoping to strengthen infrastructural construction in slower development regions, solidify facilities in transportation and communications systems, housing, schools, cultural establishment, medical care, encourage every individual region to fulfill its greatest potential, and reduce the incentive for the mobilization towards cities in order to minimize the development differences among different regions.

During the time when the cabinet led by premier Hao was in office, the government deficit increased gradually, which led to the financial difficulties facing the completion of the Six-year National Development Plan. To carry out the plan under limited financial resources, the CEPD had to determine the priorities of the execution of each regional plan while formulating the Six-year National Development Plan. For this purpose, the CEPD must evaluate the development achievements of the 23 administrative regions in Taiwan to allocate the resources in the most appropriate region. The CEPD wanted to know the answers to the following two questions:

1. What are the relative development achievements of the 23 administrative regions in Taiwan? Which regions are showing more sluggish development?
2. What is the change of regional development of the 23 administrative regions in Taiwan in recent years? Which regions possess greater potential for development?

To answer the above questions, the criteria for evaluating regional development have to be defined first. After discussion by council members of CEPD, the aspects of population characteristics, municipal planning, income levels, local finance, public facilities, medical and health care, education and culture were selected by the council as the criteria for evaluating regional development. These criteria are further defined by the following indicators:

1. Population characteristics: indicated by population density and the non-agricultural population as percentage of total population.
2. Urban planning: indicated by the urban planned area as percentage of total area, and commercial area as percentage of total area.
3. Income level: indicated by the average current household income.
4. Local finance: indicated by the local government expenditure per capita.
5. Public utilities: indicated by the number of local telephone subscribers per 100 people, and the piped water supply of population served.
6. Medical and health care: indicated by the number of physicians per 10 000 people.
7. Education and culture: indicated by the copies of newspaper and magazines sold per 1000 people and the percentage of the population over the age of 15 with an education of senior high school or above.

The definitions of each of the aforementioned 11 indicators are listed in Table 1. The larger the value of the indicator, the greater the degree of development in that region. Nevertheless, the various indicators of each region often fail to point to the same direction. For example, for a certain region, one indicator may be high, but another indicator may be very low. Therefore, the set of multiple indicators is still not capable of evaluating the current conditions of the development in every region. This paper collected the values of the above indicators in 1990 and 1983 based on the urban and regional development statistics compiled by the CEPD which are listed in Tables

TABLE 1. Performance indicators of regional development

Items	Indicators (variables)	Definitions
Population characteristics	Population density (Z_1)	Population per square kilometer
	Non-agricultural population as percentage of total population (Z_2)	Non-agricultural population/total population
Urban planning	Urban planned area as percentage of total area (Z_3)	(Urban planned area/total area) × 100%
	Commercial area as percentage of total area (Z_4)	(Commercial area/total area) × 100%
Income level	Average current household income (Z_5)	Current household income/total household
Local finance	Local government expenditure per capita (Z_6)	Local government expenditure/total population
Public utilities	Number of local telephone subscribers per 100 people (Z_7)	Number of local telephone subscribers/100 people
	The piped water supply of population served (Z_8)	(Population served/total population) × 100%
Medical and health care	The number of physicians per 10 000 residents (Z_9)	Number of physicians/10 000 population
Education and culture	Copies of newspaper and magazines sold per 1000 people (Z_{10})	Copies of newspaper and magazines sold/1000 people
	Percentage of the population over the age of 15 with an education of senior high school or above (Z_{11})	Population with senior high school or above/population aged 15 and over

2 and 3. The data were then processed by the models for measuring the relative effectiveness and effectiveness change to answer the two questions mentioned earlier, and list the priorities for achieving a balanced regional development.

3. The measurement of relative effectiveness and effectiveness change

There is a variety of methods that can be derived for measuring management performance based on the concepts of efficiency or effectiveness. Efficiency is a concept based on the physical and engineering science and refers to the relationship between inputs and outputs, where effectiveness is the degree to which the goals of an organization are met. Management is concerned with minimizing resource cost for a given output, and the goal attainment which means "doing the right thing" as expressed by Peter Drucker (Robbins, 1991). The DEA approach developed by Charnes *et al.* (1978) represents a method by which non-commensurate multiple inputs and outputs of an entity can be combined objectively into an overall measure of organizational efficiency. DEA generates a wealth of information useful in a variety of decision settings. For present purposes, its principal strength lies in its ability to combine multiple inputs and outputs into a single summary measure without requiring prespecified weights. However, we are led to consider DEA in a broader context, since there have been very few studies on the use of the DEA concept in the measurement of the relative effectiveness of an organization. But the internal and external demand for existing multiple performance ratios is likely to result in their continued use. This section will discuss the use of the DEA concept to propose a model for measuring the relative effectiveness and effectiveness change of an organization.

TABLE 2. Data for measuring regional development performance of the 23 districts of Taiwan in 1990

	District	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
R1	Taipei M.§	10 007	98·6	100	5·21	824 178	27 961	48·66	99·5	19·1	306·4	65·7
R2	Keelung C.‡	2658	99·3	53·8	5·81	612 316	13 886	30·31	97·8	11	146·3	47·6
R3	Hsinchu C.	3116	91·3	36·9	6·44	711 352	14 747	32·8	88·2	9·7	277·7	46·9
R4	Tapei P.†	1485	95·6	56·1	1·56	657 834	9235	32·92	94·8	6	222·2	46·5
R5	Taoyuan P.	1110	82·8	25·2	3·22	610 101	8962	29·32	75·3	10·9	223·3	44·6
R6	Hsinchu P.	262	58·7	4·2	0·48	606 489	13 766	21·82	42·6	5·2	150	42·7
R7	Ilan P.	211	69·5	4·5	0·36	534 220	13 045	24·41	70	8·3	174·6	34·1
R8	Taichung C.	4661	94·9	97·4	5·89	708 588	14 126	50·44	92·6	19·3	278·6	54·5
R9	Miaoli P.	301	54·6	3·8	0·46	613 163	10 646	22·99	55·4	5·8	205	40·3
R10	Taichung P.	613	71·6	16·2	1·81	626 267	8701	23·16	68·7	6·4	211·6	39·7
R11	Changhwa P.	1159	54·1	12·2	0·93	509 063	7099	23·89	73·2	6·6	129	35·2
R12	Nantou P.	131	49·5	3·1	0·15	506 819	13 778	24·74	73·2	5·7	146·9	36·8
R13	Yunlin P.	584	44·5	8·1	0·51	433 673	11 516	21·85	91·6	4·9	112	29·9
R14	Kaohsiung M.	9070	97·7	91·8	10·92	711 062	23 138	37·65	96	15·2	252·4	51·6
R15	Tainan C.	3890	92·5	100	4·34	629 513	10 848	44·09	100	13	269	47·3
R16	Chiayi C.	4291	92·2	100	11·26	627 677	8587	40·52	98·1	15·5	244·8	50·6
R17	Chiayi P.	290	48·7	7·8	0·35	414 578	14 486	17·64	85·4	3·1	110·7	29·8
R18	Tainan P.	509	60·8	15·3	1·36	491 864	10 478	17·44	96·3	5·7	166·1	34·7
R19	Kaohsiung P.	401	73·6	9·2	1·00	556 922	10 910	21·58	81·3	7·4	156·4	40·7
R20	Pingtung P.	322	60·5	6	0·33	487 693	10 476	22·53	27·3	6·3	161·1	39·2
R21	Penghu P.	756	77·9	7·2	0·66	464 845	25 646	23·5	73·6	7·2	146·6	32·4
R22	Hualien P.	76	68·4	1·8	0·15	535 071	14 561	24·15	76·8	11·5	175·4	38·4
R23	Taitung P.	73	59	2·5	0·07	424 415	19 339	19·08	70	5·7	138	33·4

†P. is the abbreviation of prefecture.
‡C. is the abbreviation of city.
§M. is the abbreviation of municipality.

Table 3. Data for measuring regional development performance of the 23 districts of Taiwan in 1983

	District	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
R1	Taipei M.	8775	98.7	100.0	5.43	462 854	17 563	33.50	99.3	14.2	329.5	54.8
R2	Keelung C.	2649	99.0	53.4	4.34	367 421	8821	21.76	92.1	7.6	152.7	40.0
R3	Hsinchu C.	2812	91.0	37.8	6.32	372 074	4557	20.37	74.8	7.6	175.1	38.3
R4	Tapei P.	1225	94.4	24.2	1.48	369 816	3753	22.49	86.8	5.3	225.1	38.0
R5	Taoyuan P.	951	82.1	16.7	2.17	311 265	4366	17.57	65.4	7.6	153.5	35.6
R6	Hsinchu P.	256	61.1	4.2	0.42	313 211	7054	16.15	34.5	4.7	111.0	33.3
R7	Ilan P.	209	69.1	4.1	0.40	259 326	5050	15.50	54.9	5.3	109.9	27.7
R8	Taichung C.	3849	92.5	98.8	5.81	394 320	7489	30.28	81.8	12.8	237.9	45.6
R9	Miaoli P.	301	60.9	3.8	0.47	301 345	5481	14.53	43.6	4.6	114.4	32.2
R10	Taichung P.	534	69.3	16.0	1.14	312 699	4154	15.38	52.6	4.7	162.3	30.2
R11	Changhwa P.	1121	57.1	11.1	0.93	301 047	4547	14.59	50.9	5.5	108.0	25.9
R12	Nantou P.	130	52.9	2.9	0.10	306 903	6024	14.57	62.9	4.2	109.8	29.4
R13	Yunlin P.	617	44.6	6.4	0.49	234 275	4485	12.31	81.2	3.3	78.5	22.1
R14	Kaohsiung M.	8214	97.5	88.1	11.80	355 454	11 075	25.48	93.2	8.9	194.2	42.0
R15	Tainan C.	3542	94.3	100.0	4.54	332 359	5464	26.59	99.8	8.4	201.0	38.3
R16	Chiayi C.	4213	91.9	100.0	4.21	350 857	6225	24.19	100.0	12.2	175.7	42.6
R17	Chiayi P.	302	46.9	6.5	0.20	269 253	5459	14.82	85.9	2.4	106.6	22.6
R18	Tainan P.	488	52.1	11.5	1.37	278 085	4551	10.41	90.2	3.8	114.1	28.1
R19	Kaohsiung P.	379	71.8	8.9	1.0	284 157	4442	12.57	73.7	4.0	122.8	31.1
R20	Pingtung P.	324	61.5	5.5	0.32	295 633	5339	11.34	21.0	4.8	117.7	31.1
R21	Penghu P.	820	67.1	5.6	0.57	288 790	11 706	12.59	37.5	4.2	137.4	25.0
R22	Hualien P.	78	67.1	1.8	0.16	292 251	800	13.04	67.3	6.2	158.2	31.9
R23	Taitung P.	80	55.5	1.0	0.4	252 011	9447	8.59	54.8	4.0	126.6	25.5

3.1. DEA AND THE RELATIVE EFFECTIVENESS

Consider five decision making units (DMUs), each having varying levels of achievement on two different performance criteria, where each DMU seeks to maximize achievement on each criterion. Figure 2 provides a two dimensional representation where each point represents the DMUs' achievement on two criteria, Z_1 and Z_2, with the hypothetical data. The goal is to find the DMUs with Pareto-optimal combinations and compare the remaining DMUs to this subset. A DMU is Pareto-optimal in its performance if none of its effectiveness with specified criterion can be increased without decreasing some of its effectiveness with other criterion (Zeleny, 1982). A DMU is not Pareto-optimal in its performance if it can be shown that some other DMU or combination of DMUs can achieve higher levels on at least one criterion without achieving less on any other criterion. It is apparent from Figure 2 that A, B, C and E are Pareto-optimal because they are not dominated by others. For example, concerning A, it is not possible to find any other DMU, or any linear combination of DMUs, which achieve more on one criterion and no less on the other. The line segments of A, B, C and E are connected to form the effectiveness possibility frontier. On the contrary, D violates the Pareto optimality conditions since movement to A is possible through an increase in Z_2 by two units, without decreasing achievement on the other criterion. Moreover, assuming all points on the segment $\overline{AB}$ represent feasible achievement levels, proportionately increasing Z_1 and Z_2 would move D to D′ where it would be optimal. We can compare D with D′, the linear combination of A, and B DMU. Both the Z_1 and Z_2 indicators of D′ are greater than those of D. In addition, D has only reached the OD/OD′ percentage of what D′ has achieved. A measure of effectiveness is implied by the relative distance that D must move to reach Pareto optimality at D′ i.e. OD/OD′, where OD is the actual objective D can achieve, OD′ is the potential objective lies on the effectiveness possibility frontier. At this stage, D′ is called the projection of D. Since OD is the linear combination of OA and OB, A and B are thus called the reference set of D. This signifies that A and B serve as the referential basis of the effectiveness of D. As A, B and C have reached the Pareto optimal, and are located in the effectiveness possibility frontier, their efficiency value is 1.

The measurement of the effectiveness of D is the measurement of OD/OD′. θ OD is the ray of OD bypassing D. The following formula must be satisfied to let θ OD fall inside the area with oblique lines:

$$\lambda_1 \begin{pmatrix} 2 \\ 5 \end{pmatrix} + \lambda_2 \begin{pmatrix} 4 \\ 4 \end{pmatrix} + \lambda_3 \begin{pmatrix} 5 \\ 2 \end{pmatrix} + \lambda_4 \begin{pmatrix} 2 \\ 3 \end{pmatrix} + \lambda_5 \begin{pmatrix} 5 \\ 1 \end{pmatrix} \geq \theta \begin{pmatrix} 2 \\ 3 \end{pmatrix} \tag{1}$$

$$\lambda_2 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 \leq 1.$$

Meanwhile, to obtain the maximum value of θ from $OD' = \theta\ OD$ in equation (1), OD′/OD can be derived from the following linear programming:

$$\begin{aligned}
\text{Max } &\theta \\
\text{s.t.} \quad &\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 \leq 1 \\
&2\lambda_1 + 4\lambda_2 + 5\lambda_3 + 2\lambda_4 + 5\lambda_5 \geq 2\theta \\
&5\lambda_1 + 4\lambda_2 + 2\lambda_3 + 3\lambda_4 + 1\lambda_5 \geq 3\theta \\
&\lambda_i \geq 0,\ i = 1, \ldots, 5;\ \theta \geq 0.
\end{aligned} \tag{2}$$
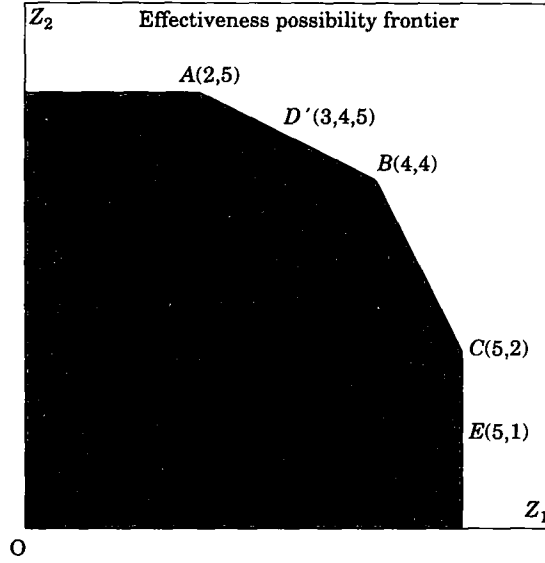
Figure 2. Effectiveness measuring with two criteria.

The solution of equation (2) is $Z^* = 1\cdot5, \lambda_1 = 0\cdot5, \lambda_2 = 0\cdot5, 1/Z^* = 0\cdot667$. This is the relative effectiveness of D, i.e. $OD/OD' = 0\cdot667$. And $OD' = \theta\ OD = 1\cdot5(2,3) = (3,4\cdot5)$.

The above example explains how the relative effectiveness under multiple criteria can be derived from a linear programming model. In general, the model for measuring an organization's effectiveness under multiple criteria $Z_1, Z_2, \ldots, Z_s$ is as the following:

$$\text{Max } \theta$$

$$\text{s.t. } \sum_{j=1}^{n} \lambda_j \leq 1$$

$$\sum_{j=1}^{n} \lambda_j Z_{i,j} \leq \theta Z_{j_0} \quad ; i = 1, \ldots, s \text{ criteria} \tag{3}$$

$$\lambda_j \geq 0 \quad ; j = 1, \ldots, n \text{ DMUs}$$

or

$$\text{Max } \theta$$

$$\text{s.t. } \sum_{j=1}^{n} \lambda_j + s^+ = 1$$

$$\sum_{j=1}^{n} \lambda_j Z_{i,j} - s_i^- = \theta\ Z_{i,j_0} \quad ; i = 1, \ldots, s \text{ criteria} \tag{4}$$

$$\lambda_j \geq 0 \quad ; j = 1, \ldots, n \text{ DMUs.}$$

The necessary and sufficient conditions for any DMU to reach the Pareto optimal are $\theta^* = 1, S_j^{-*} = S^{+*} = 0$ (Charnes *et al.*, 1978). Take the case discussed in previous sections as an example. DMU E corresponds with $\theta^* = 1$ but $S_2^{-*} = 1$. This indicates that DMU E is yet to reach the Pareto optimal. Therefore, DMU E is not relatively effective. Besides, the projection of DMU which is relative ineffective can be derived from equation (4). $\theta^*\ Z_{i,j,0} + S_i^{-*}$ can thus be considered as the management control

objective. For example, in the aforementioned case, $D'(3,4\cdot5)$ can be used as the management control objective of the organization D.

Next, let performance indicators, $Z_1 Z_2, \ldots, Z_s$, be used to evaluate the relative effectiveness of n DMUs. The effectiveness possibility set is defined as the following:

$$\mathbf{F(Z)} = \{(Z_1, Z_2, \ldots, Z_s) | (Z_1, Z_2, \ldots, Z_s) \text{ can be performed, } Z_i \in R_+^r \}$$
and let $\mathbf{Z} = (Z_1, Z_2, \ldots, Z_s) \in \mathbf{F(Z)}$.

Let the effectiveness possibility set also satisfy the following properties

P1: if $\mathbf{Z}^0 \in \mathbf{F}$ and $\mathbf{Z}^1 \in \mathbf{F}$ then $\alpha\mathbf{Z}^0 + (1-\alpha)\mathbf{Z}^1 \in \mathbf{F}$, $0 \le \alpha \le 1$.
P2: if $\mathbf{Z}^0 \in \mathbf{F}$ and $\mathbf{Z}^1 \le \mathbf{Z}^0$ then $\mathbf{Z}^1 \in \mathbf{F}$.
P3: $\mathbf{F}$ is a closed set.

P1 implies that the effectiveness possibility set is a convex set; P2 implies the lower level goal can be attained if the higher level goal has been achieved; P3. With the satisfaction of the above properties, provided there are n DMUs, the observation values of the s number of performance indicators are $\mathbf{Z}_j = (Z_{1,j}, Z_{2,j}, \ldots, Z_{s,j})$, $j = 1, \ldots, n$ (following Färe et al. (1985).) The effectiveness possibility set formed by the given observations can be written as:

$$\mathbf{F(Z)} = \left\{ \mathbf{Z} \middle| \sum_{j=1}^n \lambda_j Z_{i,j} \ge Z_{i,} \sum_{j=1}^n \lambda_j \le 1, \lambda_j \ge 0, i = 1, \ldots s; j = 1, \ldots, n \right\} \qquad (5)$$

Following Shephard's distance function (Shephard, 1970), the effectiveness distance function is defined as:

$$D(\mathbf{Z}) = \max\{\theta : \theta\mathbf{Z} \in \mathbf{F}, \ \theta > 0\} \qquad (6)$$

and the relative effectiveness is defined as $[D(\mathbf{Z})]^{-1}$. The relative effectiveness can then be derived from the linear programming in equation (3).

In a practical application, the decision maker usually designates a number of criteria in conduction performance evaluation. These criteria are usually represented with a ratio based on the input and output items. Let $\mathbf{Z} = (Z_1, Z_2, \ldots, Z_K)$ represent k number of evaluation criteria. For any of the evaluation criteria, the index is the ratio of a certain output and a certain input, that is $Z_k = Y_r/X_i$, where X_i is input Y_r is output and $, i \in \{1, 2, \ldots, m\}, r \in \{1, 2, \ldots, s\}$. Here, the s number of criteria, $\mathbf{Z} = (Z_1, Z_2, \ldots, Z_s)$ are used to evaluate the relative effectiveness of n DMUs. This can be done by substituting the ratio data into equation (3). The relative effectiveness is $[D(\mathbf{Z})]^{-1}$.

3.2. THE MEASUREMENT OF THE CHANGE OF RELATIVE EFFECTIVENESS

The method for measuring an organization's effectiveness can be extended to measure the change of an organization's effectiveness with the combination of the Malmquist productivity approach (Caves et al., 1982). As shown in Figure 3, the lines of A, B, C and D represent the effectiveness possibility frontier at period 0, and those of E, F, G and H the effectiveness possibility frontier at period t. P_0 and P_t represent the combination of Z_1 and Z_2 of an organization at period 0 and t, respectively. To propose the method
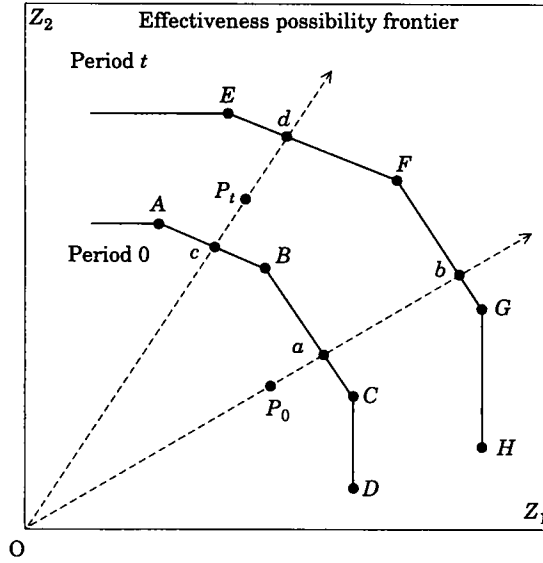
Figure 3. Effectiveness change measuring with two criteria.

for measuring the effectiveness change between the time periods 0 and t, the effectiveness distance functions of the time periods 0 and t have to be defined first as the following:

$$D^0(\mathbf{Z}^0) = \max \{\theta : \theta \ \mathbf{Z}^0 \in \mathbf{F}^0, \ \theta > 0\} \tag{7}$$

and

$$D^t(Z^t) = \max \{\theta : \theta \ Z^t \in \mathbf{F}^t, \ \theta > 0\}. \tag{8}$$

Furthermore, we define an effectiveness distance function, which is to use the effectiveness possibility frontier period t as the reference set for measuring the effectiveness of a certain DMU at period 0, as:

$$D^t(\mathbf{Z}^0) = \max \{\theta : \theta \ \mathbf{Z}^0 \in \mathbf{F}^t, \ \theta > 0\}. \tag{9}$$

From the geometric meaning of the aforementioned distance function in Figure 3, we know that:

$$D^0(Z^0) = \overline{0a}/\overline{0P_0}, \ D^t(Z^0) = \overline{0b}/\overline{0P_0}, \ D^t(Z^t) = \overline{0d}/\overline{0P_t}, \ D^0(Z^t) = \overline{0c}/\overline{0P_t}.$$

According to the Malmquist productivity index expressed by Färe *et al.* (1992), the shift in effectiveness (SIE) from period 0 to period t can be described by $\overline{Od}/\overline{Oc}$ and $\overline{Ob}/\overline{Oa}$. From equation (7), (8), and (9), the geometric average of $\overline{Od}/\overline{Oc}$ and $\overline{Ob}/\overline{Oa}$ can be used to measure the shift in effectiveness, as represented by equation (10):

$$\mathrm{SIE}_{0,t} = \left[\frac{\overline{Ob}}{\overline{Oa}} \frac{\overline{Od}}{\overline{Oc}}\right]^{1/2} = \sqrt{\frac{D^t(\mathbf{Z}^0)}{D^0(\mathbf{Z}^0)} \frac{D^t(Z^t)}{D^0(Z^t)}} \tag{10}$$

Also, the catching-up in effectiveness (CIE) from period 0 to period t can be represented by equation (11),

$$\text{CIE}_{0,t} = \frac{D^0(\mathbf{Z}^0)}{D^t(\mathbf{Z}^t)} = \frac{\overline{OP/Od}}{\overline{OP_0/Oa}}, \tag{11}$$

which represents the ratio between the relative effectiveness of a DMU at period t against that at period 0. $CIE_{0,t} > 1$ indicates that the relative effectiveness of a DMU has a greater improvement at period t than at period 0. $\text{CIE}_{0,t} \times \text{SIE}_{0,t}$ can be used to measure the total effectiveness change (TEC) between the time periods 0 and t; that is:

$$\text{TEC}_{0,t} = \text{CIE}_{0,t} \times \text{SIE}_{0,t} = \frac{D^0(\mathbf{Z}^0)}{D^t(\mathbf{Z}^t)} \sqrt{\frac{D^t(\mathbf{Z}^0)}{D^0(\mathbf{Z}^0)} \frac{D^t(\mathbf{Z}^t)}{D^0(\mathbf{Z}^t)}}$$

$$= \sqrt{\frac{D^t(\mathbf{Z}^0)}{D^t(\mathbf{Z}^t)} \frac{D^0(\mathbf{Z}^0)}{D^0(\mathbf{Z}^t)}} \tag{12}$$

4. Results

Based on the model for measuring relative effectiveness shown in equation (4), the regional development achievement of the 23 administrative regions in the Taiwan area was evaluated according to the pre-selected indicators of regional development described in the previous sections. The values of the relative effectiveness and the slack variables corresponding to each of the indicators are listed in Table 4 in the order of the value of the relative effectiveness. A larger value of the relative effectiveness signifies a more-advanced degree of regional development, while a smaller value indicates a sluggish regional development. The more sluggish the regional development, the more urgent that region's need of a national development plan.

The results indicate that the relative effectiveness of Taipei M., Kaohsiung M., Keelong C., Taichung C., Tainan C. and Chiai C. is 1. The relative effectiveness of the remaining 18 regions is smaller than 1. Among these 18 regions, Hsinchu shows the largest value of the relative effectiveness. The results are in unison with the division of administrative regions in Taiwan area. Taipei M. and Kaohsiung M. are the two municipalities under the direct jurisdiction of the Executive Yuan. The four cities under the jurisdiction of the provincial government, Keelong C., Taichung C., Tainan C. and Chiai C., are better-developed regions. As for Hsinchu C., the latest cities to come under the jurisdiction of the provincial government, the relative effectiveness reaches 0·995. In addition, it is clear that the conditions for a district to be Pareto-optimal are $\theta^* = 1$ and $S^{-*} = S^{+*} = 0$, where "*" indicates an optimal solution. If a district is not effective, based on the constraints in equation (4), the projection of each relative ineffective district can be derived. For example, the optimal S_{11}^- for Hsinchu City is 12·6 as shown in Table 4. Together with $\theta^* = 0·995$, this result indicates that $\theta^* Z_{11} + S_{11}^{-*} = 0·995 \times 46·9 + 12·6 = 59·26$ can be used as the guide and the potential objective for the regional development of Hsinchu city.

Moreover, the model for measuring the effectiveness change presented in this paper is used to examine the change of the regional development of each administrative region

TABLE 4. Ranking relative effectiveness of regional development of the 23 districts in Taiwan in 1990

District	Effectiveness	Slack values of each criterion										
		Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}
Taipei M.	1	0	0	0	0	0	0	0	0	0	0	0
Keelung C.	1	0	0	0	0	0	0	0	0	0	0	0
Taichung C.	1	0	0	0	0	0	0	0	0	0	0	0
Kaohsiung M.	1	0	0	0	0	0	0	0	0	0	0	0
Tainan C.	1	0	0	0	0	0	0	0	0	0	0	0
Chiayi C.	1	0	0	0	0	0	0	0	0	0	0	0
Hsinchu C.	0·9950	6479	2·45	59·01	0	46 172	11 158	11·21	5·90	7·85	0	12·60
Tapei P.	0·9835	4842	0	25·68	6·72	0	8956	3·30	0·83	7·53	0	2·43
Tainan P.	0·9630	3373	29·38	84·11	2·93	119 125	0	25·99	0	7·09	96·59	11·30
Penghu P.	0·9172	9183	13·67	92·15	4·49	317 373	0	23·04	19·26	11·25	146·57	30·38
Yunlin P.	0·9164	3867	44·56	91·16	3·87	175 848	0	20·71	0	8·27	150·55	16·52
Chiayi P.	0·8555	5726	37·74	90·88	4·24	214 133	0	25·10	0	11·55	152·90	19·01
Taoyuan P.	0·8524	7212	0	64·44	5·49	0	11 660	5·61	8·67	2·66	0	0·63
Kaohsiung P.	0·8141	5112	3·81	88·70	3·36	0	2243	15·86	0	5·62	87·38	2·46
Hualien P.	0·7698	6675	6·52	97·66	4·56	26 212	0	14·87	0	0·94	58·78	6·09
Taichung P.	0·7599	9200	4·37	78·68	2·83	0	16 510	18·18	9·09	10·68	27·93	13·45
Miaoli P.	0·7440	9602	25·21	94·89	4·59	0	13 651	17·76	25·04	11·30	30·85	11·53
Nantou P.	0·7406	5673	20·53	74·63	3·79	0	0	6·11	0	6·28	62·06	2·90
Hsinchu P.	0·7359	9651	18·83	94·29	4·56	0	9254	19·01	41·61	12·03	102·56	7·67
Changhwa P.	0·7332	4345	20·75	83·36	3·36	0	6860	13·03	0	6·03	105·51	5·41
Ilan P.	07064	7393	0	81·60	4·80	0	4706	9·03	0	4·84	15·11	11·51
Taitung P.	0·7034	9736	14·56	96·45	5·09	215 493	0	21·41	0	10·83	109·19	17·71
Pingtung P.	0·6132	8763	0	85·70	4·73	8097	9500	10·12	54·81	8·03	28·02	0

TABLE 5. Ranking relative effectiveness change of regional development of the 23 districts in Taiwan over the years from 1983 to 1990

| District	$D^{90}(Z^{90})$	$D^{83}(D^{83})$	$D^{90}(D^{83})$	$D^{83}(Z^{90})$	SIE	CIE	EC
Penghu P.	1·0903	1·4711	1·4721	0·6848	1·2622	1·3493	1·7031
Miaoli P.	1·3441	1·5360	1·6275	0·7549	1·3735	1·1428	1·5696
Taitung P.	1·4216	1·7788	1·7788	0·9082	1·2511	1·2513	1·5655
Hualien P.	1·2990	1·4607	1·7829	0·8650	1·3539	1·1245	1·5224
Hsinchu P.	1·3589	1·4778	1·6212	0·7632	1·3976	1·0875	1·5199
Changhwa P.	1·3638	1·5375	1·7359	0·9092	1·3014	1·1274	1·4671
Taichung P.	1·3160	1·4250	1·4275	0·7391	1·3355	1·0828	1·4462
Nantou P.	1·3503	1·5081	1·5898	0·9133	1·2484	1·1169	1·3943
Hsinchu C.	1·0050	1·0820	1·0863	0·6507	1·2452	1·0766	1·3406
Kaohsiung P.	1·2283	1·3412	1·3518	0·8311	1·2205	1·0919	1·3327
Ilan P.	1·4156	1·4325	1·4363	0·8664	1·2799	1·0119	1·2952
Taipei M.	1	1	0·9299	0·5616	1·2868	1	1·2868
Pingtung P.	1·6309	1·5656	1·6116	0·9491	1·3300	0·9600	1·2767
Taoyuan P.	1·1731	1·1954	1·2074	0·7587	1·2497	1·0190	1·2734
Taichung C.	1	1·0045	1·0121	0·6532	1·2420	1·0045	1·2476
Taipei P.	1·0168	1·0472	1·0478	0·7036	1·2025	1·0299	1·2384
Kaohsiung M.	1	1	0·9339	0·6193	1·2280	1	1·2280
Chiayi C.	1	1	0·9997	0·6782	1·2141	1	1·2141
Tainan C.	1	1	1	0·7353	1·1662	1	1·1662
Keelung C.	1	1	1·0027	0·7559	1·1517	1	1·1517
Yunlin P.	1·0912	1·2315	1·2315	1·0673	1·0111	1·1286	1·1411
Tainan P.	1·0384	1·1086	1·1086	0·9410	1·0505	1·0676	1·1215
Chiayi P.	1·1689	1·1641	1·1641	1·1164	1·0232	0·9959	1·0190
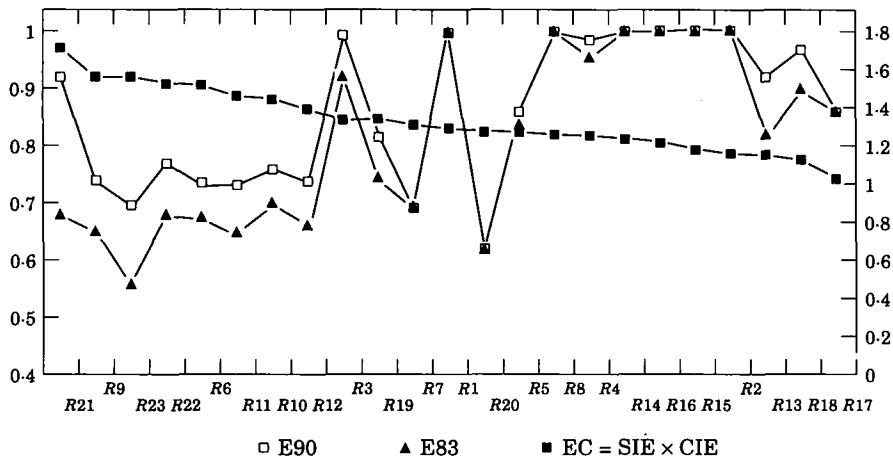
Figure 4. Diagram of relative effectiveness and effectiveness change of the 23 districts in Taiwan.

over the past 8 years from 1983 to 1990. The results are listed in Table 5 in the order of the value of effectiveness change. The correlation coefficients between the effectiveness change and the following items: shift in effectiveness, degree of catching-up in effectiveness, the relative effectiveness in 1983 and the relative effectiveness in 1990 are listed in Table 6.

The results indicate that for the regional development of the 23 administrative regions in Taiwan area between 1983 and 1990, the effectiveness change is positively correlated with the shift in effectiveness and the degree of catching-up in effectiveness. But the change is negatively correlated with the relative effectiveness in 1983 as well as that in 1990. This signifies that during the 8 years between 1983 and 1990, the regions which enjoyed greater regional development are those with more sluggish development in 1983 as well as in 1990. The relationships among the relative effectiveness in 1983, the relative effectiveness in 1990 and the effectiveness change between 1983 and 1990 are shown in Figure 4. From this figure, it is obvious that the smaller the relative effectiveness in 1983, the greater the effectiveness change over the 8 years, and vice versa. For example, Penghu P., Miaoli P., Taitung P, Hualien P. and Hsinchu P. have a relatively less impressive value of relative effectiveness in 1983. But their effectiveness change over the past 8 years is relatively greater than that in other regions. On the other hand, the regions which have a relatively more-advanced relative effectiveness in 1983, such as Kaohsiung M., Chiai C., Tainan C. and Keelong C., produce a smaller effectiveness change over the past 8 years. The results indicate that according to the 11 regional development indicators in question the difference among the regional development of each of the administrative regions in Taiwan area between 1983 and 1990 was getting smaller.

The above analysis is sufficient to answer the questions posted by the CEPD, and serve as a reference for the formulation of a regional development plan. We represent the values of relative effectiveness for measuring the regional development of 23 regions with a horizontal axis. A smaller value represents a region with less development at present, which is considered a region more urgently in need of national development. A larger value represents a region with more-advanced development, which is considered a region less urgently in need of national construction. Moreover, we represent the

TABLE 6. Correlation coefficients between effectiveness change and relative effectiveness of the 23 districts in Taiwan

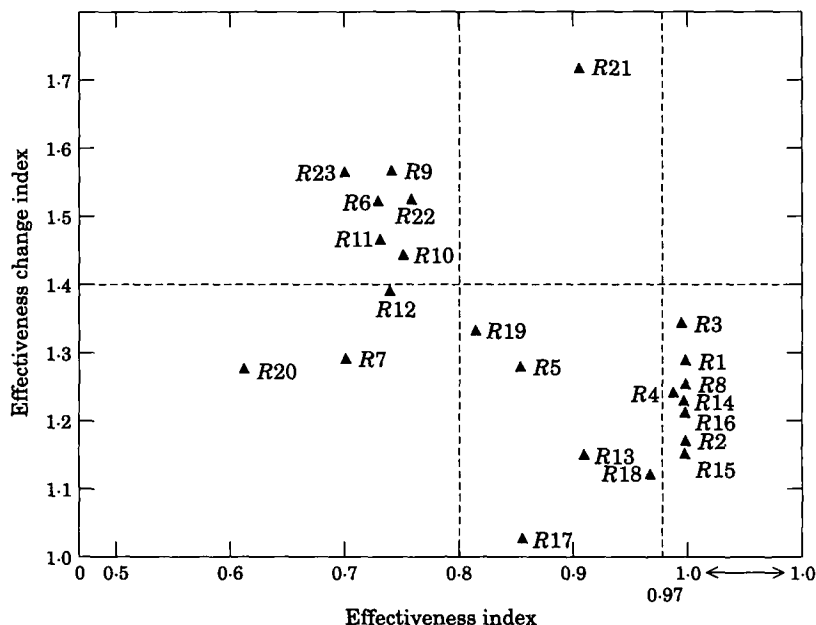| Relative effectiveness	Effectiveness change
Relative effectiveness of regional development in 1983	−0·7097
Relative effectiveness of regional development in 1990	−0·4979
Shifts in effectiveness of regional development from 1983 to 1990	0·7534
Degree of catching-up in effectiveness of regional development from 1983 to 1990	0·7732

Figure 5. Scatter of achievement and change of regional development of 23 districts in Taiwan.

value of the effectiveness change for measuring the regional development of 23 regions with a vertical axis. A smaller value indicates a region with a slower pace of development over the past 8 years, which is regarded as a region with less potential for regional development. A larger value indicates a region with a faster pace of development over the past 8 years, which is regarded as a region with greater potential for regional development. The scatter is shown in Figure 5. Based on the urgency of the demand of the national development plan and the potential for regional development, the 23 regions in Taiwan can be classified into five categories:

1. Regions with less development but a fast pace of change: the seven prefectures of Taitung, Hsinchu, Miaoli, Hualien, Changhwa, Nantou and Taichung have a value of relative effectiveness below 0·8, but an effectiveness change value over 1·4. The current development of these regions is less advanced, and their need for national development plan is more urgent. In addition, these regions had a fast pace of change in regional development over the past 8 years, showing a

greater potential for regional development. Therefore, these regions can qualify as the top priorities for the implementation of national development.

2. Regions with less development and a slow pace of change: the prefectures of Pingtung and Ilan have a relative effectiveness below 0·8, and an effectiveness change below 1·4. The current development of these regions is less advanced, and the need for national development plan is quite urgent. However, the change of regional development in these regions over the past 8 years is rather limited, and so is the potential for regional development.

3. Regions with medium development and a fast pace of change: the relative effectiveness of the Penghu prefecture is between 0·8 and 0·97, and the effectiveness change value is over 1·4. This region has an intermediate current development and just an average urgency of the need for a national development plan. But this region had a fast pace of change in regional development over the past 8 years, and thus possesses good potential for regional development.

4. Regions with medium development and a medium pace of change: the five prefectures of Kaohsiung, Taoyuan, Chiai, Yulin and Tainan have a value of relative effectiveness between 0·8 and 0·97, but an effectiveness change value below 1·4. These regions have an intermediate current development and just an average urgency of the need for national development plan. The pace of change in regional development over the past 8 years is just an average for these regions, and so is the potential for regional development.

5. Regions with advanced development but a slow pace of change: the two municipalities of Taipei and Kaohsiung, five cities of Taichung, Hsinchu, Keelong, Tainan and Chiai, and the prefecture of Taipei have a relative effectiveness over 0·8, but an effectiveness change value below 1·4. The current development of these regions is rather advanced, and their need of national development plan is less urgent. In addition, these regions had a slow pace of change in regional development over the past 8 years, indicating limited potential for regional development.

5. Conclusion

In Taiwan, the objective of the Six-year National Development Plan is to achieve balanced overall development. To carry out the various plans for a balanced regional development under a limited budget, the urgency of the need of national development by each administrative region, as well as the potential for development possessed by each region, have to be evaluated and weighed to determine the priorities of all regional development plans.

Based on the Pareto-optimal concept, this paper extends the DEA approach for measuring relative efficiency by Charnes *et al.*, and proposes a mathematical programming model, which is capable of measuring the relative effectiveness of an organization in terms of performance ratios under multiple criteria. At the same time, this paper combined the model for measuring effectiveness with the Malmquist productivity approach expressed by Färe *et al.*, and extended the model to become a model for measuring the effectiveness change of an organization. The model presented in this paper provided useful information for the formulation of a regional development plan in Taiwan and offered the solutions for the cases in this paper.

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