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Measuring the relative efficiency of police precincts using data envelopment analysis

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Abstract

Data envelopment analysis (DEA) is used to measure the relative efficiency of the 14 police precincts in Taipei city, Taiwan. Our results indicate how DEA may be used to evaluate these police precincts from commonly available police statistical data for the years 1994–1996. To sharpen our efficiency estimates, we use window analysis, slack variable analysis, and output-oriented DEA models with both constant and variable returns to scale. The problem of the presence of non-discretionary input variables is explicitly treated in the models used. Potential improvements in technical efficiency of police precincts are examined by readjusting the particular output/input indicators. The analysis indicates that differences in operating environments, such as resident population and location factors, do not have a significant influence upon the efficiency of police precincts. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The purpose of this paper is to measure the relative efficiency of the Taipei Municipal Police Precincts with data from 1994–1996, using a two-stage procedure. In the first stage, data envelopment analysis (DEA), as put forward by Charnes et al. [1], is used to construct a scalar measure of efficiency for all police precincts. In the second stage, multiple regression is employed to analyze external factors or operating environments that might explain the variation in technical efficiencies across police precincts. The results of this study can be used to assist the Taipei Police Department in delivering better and more efficient services to the community.

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The inexorable rise in reported crime in recent years—96,810 cases in the year 2000 in Taipei city, up 103% from 1991, and increased expenditure for police services, NT$ 1,290,564 (US$1 = 33 NT$) reported in the year 2000, up 64.5% from 1992—have brought crime to the forefront of public debate. Clearly, analyzing police performance would be a useful objective for improving police efforts in crime management. To date, few studies undertaken by the Police Department have helped police managers and officers identify how management systems can be changed to improve factors underlying efficiency of police operations.

Since the police force's operations represent a significant spending of tax-payers' money, it is vital to ensure the economic, effective and efficient provision of police services. However, due to their complexity, traditional performance measurement techniques have not been very effective in identifying and disseminating best police practices. This paper will address the above-stated concerns. In particular, we report on a developmental study of DEA as a method for evaluating the relative efficiency of police precincts in Taipei city. A precinct refers to the management of police units in a specific administration district of Taipei, which is responsible for the prevention and investigation of crime. To the best of our knowledge, this research is the first DEA study of police forces in Taiwan.

DEA has many desirable features, which is why it was used here to measure the relative efficiency of 14 Taipei Municipal Police Precincts. These qualities include the following:

(1) It provides a single aggregate measure of the relative efficiencies of police precincts in terms of their utilization of input factors to produce desired outputs;
(2) it can handle non-commensurate multiple output and input factors;
(3) it can adjust for factors outside the control of the unit being evaluated;
(4) it is not dependent on a set of a priori weights for the inputs or the outputs;
(5) it can provide targets for increasing outputs and/or conserving inputs for an inefficient police precinct to become efficient; and
(6) it maintains equity in performance assessment.

Furthermore, it is theory-based, transparent and is a reproducible computational procedure. It has several advantages over traditional approaches such as ratio analysis and regression analysis (see [2]). A major advantage is that DEA has been empirically validated many times over. As Golany [3] points out, DEA is emerging as the leading method for efficiency evaluation, in terms of both the number of research papers published and the number of applications to real world problems. We shall assume throughout this paper some knowledge of DEA. Readers not familiar with DEA are referred to [4,5].

Given our aim above, we investigated the following research questions:

(1) What input and output measures can be used to assess performance of the police precincts in question?
(2) Which precincts are most efficient?
(3) What suggestions can we provide for inefficient precincts to improve their efficiency?
(4) Do differences in operating environments, such as location and socioeconomic factors, have a significant influence upon the efficiency of police precincts?

The paper is organized as follows. It first discusses related prior studies that have influenced the current work. Next, a preliminary data analysis regarding the selection of input and output measures for use in a DEA model is presented. There then follows a section introducing the methodology used in the evaluation of police precinct performance. The empirical results obtained from the DEA assessment are presented and discussed. The paper concludes with a summary of the findings regarding the use of DEA to improve the performance of police services.

2. Review of literature

In the last decade, several DEA-based police performance studies have described practical implementations in the UK and Australia (i.e., Audition Commission [6]; NSW Treasury [7]). Published applications of DEA to police services can also be found in Thanassoulis [8] and Carrington et al. [9]. These papers provide important contributions to this area and furthered our understanding of police performance and the use of DEA to estimate efficiency. We briefly outline these earlier studies in terms of their production model, sample size, and limitations.

Thanassoulis [8] used an output-orientated CCR model (Charnes, Cooper and Rhodes [1]) to analyze 41 police forces in England and Wales using data for the years 1992–1993. The production model consisted of four inputs: police officers employed at each force, number of violent crimes, burglaries, and other crimes recorded; and three outputs: number of "clear ups" of violent crime, burglary, and other crimes recorded. For a closer view of performance, "manpower efficiency" and "clear up efficiency" were examined. Manpower efficiency was measured using one input (officers) and three outputs (number of violent crimes, burglaries, other crimes recorded). Clear up efficiency was measured with three inputs (number of violent crimes, burglaries, other crimes recorded; and three outputs (number of clear ups of violent crime, burglary, and other crimes recorded). The author concluded that raising staffing levels would lead to more crimes being cleared. It is important to highlight his attempt to capture, in the production model, the input–output weights and the identification of efficient peer forces for each inefficient force. However, there appear certain weaknesses in the assessment. Chief among these was the fact that the efficiency ratings of some forces could be based on a downgrading of the importance of certain output variables, often in a counter-intuitive way. Another weakness was that many inefficient forces had policing environments dissimilar to those of their efficient peers and so were not strictly comparable to one another. Also, from a technical point of view, the CCR model used could not examine whether technical and scale efficiencies existed for any other police forces (see [10]). Specifically, increasing or decreasing returns as well as constant returns to scale were not identified (see [11] for a relevant discussion).

Carrington et al. [9] examined the technical efficiency of the New South Wales (NSW) Police Service in 1994–1995, using a two-stage procedure. In the first stage, input-orientated CCR and BCC (Banker, Charnes and Cooper [10]) models were used to compute the technical efficiencies of 163 police patrols. Their production model consisted of three inputs (police officers, civilian employees, and police cars) and five outputs (number of offences, arrests, summons, major car accidents recorded, and kilometers traveled by police cars). In the second stage, Tobit regression was used to analyze external factors or operating environments of patrols (i.e., proportion of young people, proportion of government housing and location). Returns to scale were also addressed in their paper. The authors concluded that (1) NSW police patrols could, on average, reduce input usage by 13.5% through better management, and by 6% if the patrols could be restructured to achieve optimal scale; and (2) differences in operating environments, such as location and socioeconomic factors, did not have a significant influence on the efficiency of police patrols.

Carrington et al. [9] enhanced their study by addressing technical and scale efficiencies for police patrols, the possibility of increasing or decreasing returns to scale, and analyzing operating environments that might help explain the variation in technical efficiencies across police patrols. However, their study has several limitations. First, they did not provide a statistical justification for use of their inputs and outputs in the DEA model. Second, their results suggest that, to be efficient, an inefficient police patrol must reduce its input usage by a certain percentage, but this seems somewhat paradoxical. Why are its levels of outputs not increased? Is it because an input-orientated model was used in their study? Finally, inefficient units and their efficient peers were not identified.

In conducting our study, we provide a statistical justification for the inputs and outputs used in the DEA model. We use output-orientated CCR and BCC models to examine the overall, technical, and scale efficiencies for all police precincts studied. Further, we identify inefficient units and their efficient peers, deal with the possibility of increasing or decreasing returns to scale, and specify potential improvements in technical efficiency of the precincts. Finally, multiple regression is used to investigate the influence of operating environments on the technical efficiency of police precincts.

3. Preliminary data analysis

The first step in applying DEA is to identify the set of input and output measures to be included in the analysis. The objective is to select a set of inputs and outputs that are relevant to performance appraisal and for which a moderate statistical relationship exists. In some cases, the appropriate factors can be identified by experienced police administrators or from prior research. In other situations, when data are available, a multivariate statistical analysis may be necessary to determine:

(1) which outputs are intercorrelated—some of the outputs can be deleted from the model if statistical analysis shows them to be redundant;
(2) which inputs are intercorrelated—some of the inputs can be deleted if they are redundant;
(3) which inputs and outputs are related; and
(4) the direction of the relationship, i.e. whether it is positive or negative.

3.1. Conceptual input/output measures

Prior studies of police performance suggest that the following inputs and outputs for police precincts should be considered in our study:

(1) *input measures:*
- number of various criminal activities recorded, e.g., number of burglaries;
- number of police officers employed;

- number of civilian employees;
- level of expenditure for a police precinct;
- capital equipment used for police activities, e.g., number of police cars and computers; and
- other inputs, e.g., the number of civilian employees.

(2) *output measures:*
- number of various crime clear ups;
- number of various non-crime activities recorded, e.g., activities for traffic control and emergency first aid care;
- number of police activities to prevent crime and investigate criminal cases, e.g., patrol and official inspection; and
- other outputs, e.g., quality of services.

3.2. Available input/output measures

In an ideal world with no data limitations, our DEA model of police precincts would include all the inputs a police precinct uses and all the outputs it produces to deliver service to the public. Since it was difficult to obtain first-hand data from the Taipei Police Department, we only used secondary data.

Law and order is a high priority of the Taipei City Government. The Police Department has thus developed several objectives for its services:

- to prevent crime;
- to enforce the law; and
- to protect, help and reassure the public.

In particular, the Department aims at preventing crime and bringing down high crime rates as major tasks in order to protect public safety. Consequently, the number of crimes recorded and the number of crimes cleared up were considered to be important inputs and outputs. However, there are a large variety of crimes ranging from multiple murder to vandalism. Retention of numerous crime categories would overcomplicate the analysis, obscuring an overview of the performance of each Precinct. For purposes of building a simple, yet fair picture of crime levels and clear up at each Precinct, we used group crimes as categorized by the Police Department in police statistics publications. Group crimes are of three types:

- offence (felonious and violent),
- burglary, and
- ‘other’.

Information on numbers of civilian employees, capital equipment used, and various non-crime activities recorded was not available. While information on expenditure for police services was available, the amount budgeted for an included police precinct was not specified. Therefore, these input and output variables were excluded from the DEA model.

A crime was deemed “cleared up” if it had resulted in a summons, or charge, caution, no further action deemed appropriate, or was deemed to have been ‘taken into consideration’ with some other cleared up offence. Using these three crime categories and available information conveying input, the following variables were specified for assessing the performance of police precincts:

(1) *input variables:*
- number of police officers employed (x_1);
- number of burglaries recorded (x_2);
- number of offence crimes recorded (x_3); and
- number of other crimes recorded (x_4).

(2) *output variables:*
- number of burglary clear ups (y_1);
- number of offence crime clear ups (y_2); and
- number of other crime clear ups (y_3).

We used annual data for the years 1994, 1995, and 1996. Table 1 presents descriptive statistics for our data set. Input and output data are reported as the total number throughout the year and can be found in the *Taipei Municipal Police Department Statistics* [12–14]. We did not use data covering the years 1996–1999 because annual statistical data for these police precincts published by Taipei City Government [15] were not available. Only annual data for the Police Department were reported.

3.3. Correlation and regression analysis

As an initial step, correlations were calculated to analyze the candidate set of inputs and outputs and identify variables that are highly interrelated. Table 2 shows correlations among all study input and output variables. Some key intercorrelations include the following:

(1) $R = 0.78$ for 'the number of police officers' and 'the number of other crimes recorded'.
(2) $R = 0.83$ for 'the number of offences recorded' and 'the number of other crimes recorded'.

Table 1
Descriptive statistics for the 14 police precincts studied (42 observations)

		Mean	Standard deviation	Minimum	Maximum
Inputs					
Police officers	(x_1)	337.64	98.62	191	547
Burglaries	(x_2)	835.74	682.61	131	2559
Offences	(x_3)	140.00	105.05	25	472
Other crimes	(x_4)	897.64	528.27	322	2310
Outputs					
Burglary clear ups	(y_1)	343.14	162.61	90	739
Offence clear ups	(y_2)	95.60	52.49	18	240
Other crime clear ups	(y_3)	946.02	521.46	339	2142

(3) $R = 0.90$ for 'the number of burglary clear ups' and 'the number of other crime clear ups'. Clearly, police precincts that do well on burglary clear ups also do well on other crime clear ups. This finding is consistent with the work of Thanassoulis [8].
(4) $R = 0.90$ for 'the number of offence clear ups' and 'the number of burglary clear ups'.
(5) $R = 0.87$ for 'the number of police officers' and 'the number of burglary clear ups'.
(6) $R = 0.91$ for 'the number of offence clear ups' and 'the number of offences recorded'.
(7) $R = 0.91$ for 'the number of offence clear ups' and 'the number of other crimes recorded'.
(8) $R = 0.94$ for 'the number of other crime clear ups' and 'the number of other crimes recorded'.

The next step involved examination of the relations between inputs and outputs, and the direction of these relationships (i.e., positive or negative). To determine the appropriate model specification, multiple regression was utilized. The regression results in Table 3 show that a plausible, but not proven, production relationship exists between the input and output measures. We do, however, note that it is conceptually incomplete, since some data for inputs and outputs simply could not be obtained.

The input variables explained 87.4% of the variation in the output of burglary clear ups; 92.44% of offence clear ups; and 91.79% of other crime clear ups. The results in Table 3 suggest

Table 2
Correlation coefficients among inputs and outputs

	Input variable				Output variable		
	x_1	x_2	x_3	x_4	y_1	y_2	y_3
x_1	1	0.69	0.76	0.78	0.87	0.85	0.83
x_2	0.69	1	0.85	0.63	0.75	0.76	0.56
x_3	0.76	0.85	1	0.83	0.80	0.91	0.75
x_4	0.78	0.62	0.83	1	0.85	0.91	0.94
y_1	0.87	0.75	0.80	0.85	1	0.90	0.86
y_2	0.85	0.76	0.91	0.91	0.90	1	0.89
y_3	0.83	0.56	0.75	0.94	0.86	0.89	1

Table 3
Regression results on input and output variables for the 14 police precincts (42 observations)

Input factors	Output measures		
	y_1	y_2	y_3
x_1	0.6751[a]	0.1277[a]	1.5344[a]
x_2	0.0863[a]	−0.0019	−0.0297
x_3	−0.2927	0.2269[a]	−0.6934
x_4	0.1401[a]	0.0356[a]	0.8449[a]
Constant	−41.6658	−9.7111	−208.625
R^2	0.8740	0.9244	0.9179

[a] Statistically significant at the 0.01 level.

that inputs related to police officers and crimes can be viewed as positive factors; that is, increasing the input factor generally led to an increase in an output factor. For the other inputs, number of burglaries recorded and officers, the relationships were weaker. These results provide some assurance that our model using four inputs and three outputs alone is a good representation of police performance.

4. Methodology

Consistent with managerial goals, our study focuses exclusively on the performance of police officers employed at a police precinct. From a technical perspective, we use some important extensions to DEA models in our study. In particular, we perform window analysis (see Charnes et al. [16]) to deal with the degrees of freedom problems in using seven measures to evaluate 14 precincts/decision making units (DMUs). To perform the efficiency analysis, we used a three-year window. Each DMU is thus represented as if it were a different DMU for each of the three successive years in a window (94, 95, 96) with a resulting analysis of 42 ($=3\times 14$) DMUs. As Klopp [17] points out, window analysis can be used to analyze trends and potential stability problems which are also considered in this paper.

Some of the input variables are non-discretionary. They are in the forms of (1) burglaries, (2) offences, and (3) other crimes. Only the number of police officers in each precinct is discretionary. For these, we used the modified DEA mode proposed by Banker and Morey [18].

We used CCR and BCC models to measure overall, technical, and scale efficiencies for the precincts. To investigate returns to scale (RTS), we calculated the sum of all lambdas for each precinct to determine the type of scale efficiency affecting these precincts, whether increasing or decreasing. According to Banker and Thrall [11], if the sum of all lambdas for a DMU is greater than 1.0 then there are decreasing returns to scale (DRS), and if the sum of all lambdas is less than 1.0 there are increasing returns to scale (IRS). Constant returns to scale occur when the sum of lambdas for a DMU equals 1.0. (An excellent discussion of these issues can be found in Cooper et al. [5].)

Although the efficiency scores obtained from solving linear programming problems for DEA models represent the ability of management to convert inputs into outputs at the current scale of operation, it is possible that some other external factors, beyond the control of management, may affect efficiency. We are thus interested in determining which external factors have influence on variations in technical efficiency across police precincts, and in which direction. Multiple regression analysis was used to estimate the relationship between technical efficiency scores and operating environmental factors. Specifically, we estimated the following model:

$$TE = \alpha + Z\beta + u$$

where TE is a vector ($J\times 1$) of technical efficiency for J police precincts, the scalar α and the ($R\times 1$) vector β are unknown parameters to be estimated, Z is a ($J\times R$) matrix of environmental factors, and u is a ($J\times 1$) vector of residuals.

4.1. Production model

Based upon our preliminary analysis, we constructed a production model incorporating all four inputs and three outputs in seeking to measure the relative efficiency of police precincts in Taipei city.

The set of input–output variables was used so that the efficiencies obtained would reflect the extent to which clear ups in a precinct could rise given its crime levels and manpower if the precincts were to perform as well as the best precincts found. Data reflecting computers, cars, etc. were ignored, since capital equipment employed by all police precincts are fairly homogeneous. In addition, these data were not available. Our assessment adopted an output orientation, consistent with the notion that crime levels are largely outside the control of the police and efficient operations should, at least in the short run, result in higher clear ups rather than lower crime levels.

The assessment of police precinct performance in this paper is similar to that of Thanassoulis [8] in that we focus on crime clear ups. We also assumed that constant returns to scale hold in converting crimes to clear ups. As Thanassoulis [8] points out, this assumption is likely to be safe if there is no reason to believe that the proportion of harder-to-clear cases depends on the actual portion of cases cleared. The number of harder-to-clear cases may be proportionately greater the larger the proportion of crime cases cleared.

As noted above, we used output-oriented DEA models. In particular, the CCR model was used to examine relative efficiency, while the BCC model was used to estimate technical and scale efficiencies. Frontier Analyst, a DEA-based software package developed by Banxia Software Ltd [19] was used for mathematical computations.

4.2. The sample

Our sample consists of 14 police precincts in Taipei city, Taiwan, and constitute all the police precincts in the city. Fig. 1 is a map of Taipei city showing the locations of these precincts. Other police agencies, such as Criminal Investigation Corps, Police Mobile Unit, Traffic Police Corps, Juvenile Police Corps, and Policewoman Corps are excluded from the study since they are organizationally separate forces.

5. Results

5.1. Window analysis

Table 4 represents a window analysis of overall, technical, and scale efficiencies, as well as RTS results for the 14 precincts studied. Note that (1) almost 76% of the 42 DMUs were found to be overall inefficient with an average overall efficiency score of 86.97; (2) approximately 48% were technically inefficient with an average technical efficiency score of 92.61; (3) nearly 76% were scale inefficient with an average scale efficiency score of 93.83; and (4) the returns to scale categories for IRS, CRS, and DRS were 32, 10, and 0 DMUs, respectively. Overall efficiency ratings of 100, 100 and 100 for three separate DEA evaluations indicated that Chungshan Precinct and Chungcheng

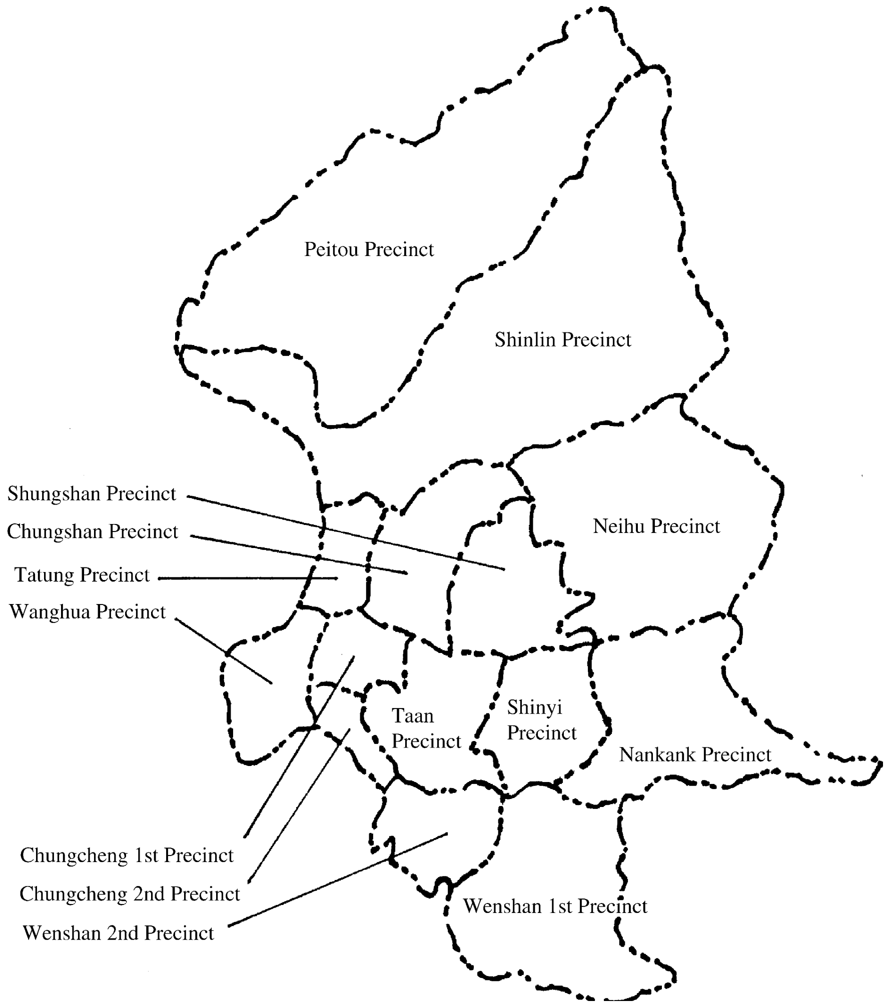

Fig. 1. A map of Taipei city showing the locations of the 14 police precincts studied.

second Precinct were overall efficient across the three study years. These two precincts were also technically and scale efficient; Taan Precinct was technically efficient over the three years.

In total, our DEA assessment found that 10 of the 42 DMUs had an overall efficiency rating of 100%. These included Nankang Precinct (1994), Chungcheng first Precinct (1994, 1996), Chungcheng second Precinct (1994, 1995), Chungshan Precinct (1994–1996), Neihu Precinct (1996) and Tatung Precinct (1994). The other precincts were overall inefficient, since their efficiency ratings were less than 1.0. 20 of the 42 DMUs had a technical efficiency rating of 100%. The efficient police precincts were Chungcheng first Precinct (1994, 1996), Chungcheng second Precinct (1994), Chungshan Precinct (1994–1996), Nankang Precinct (1994, 1995), Neihu Precinct (1996), Shihlin Precinct (1996), Sungshan Precinct (1996), Taan Precinct (1994–1996), Tatung Precinct (1994), Wanhua Precinct (1994), Wenshan first Precinct (1994) and Wenshan second Precinct (1994, 1995). The other precincts were found to be technically inefficient.

Table 4
Efficiency of the 14 police precincts for the period 1994–1996

Precinct	Term	DMU code[a]	Efficiency measures (%)			RTS
			Overall	Technical	Scale	
Tatung	1994	1-94	100	100	100	CRS
	1995	1-95	92.31	92.40	99.90	IRS
	1996	1-96	88.95	89.13	99.80	IRS
Wanhua	1994	2-94	99.92	100	99.92	IRS
	1995	2-95	84.71	86.06	98.43	IRS
	1996	2-96	91.47	93.98	97.33	IRS
Chungshan	1994	3-94	100	100	100	CRS
	1995	3-95	100	100	100	CRS
	1996	3-96	100	100	100	CRS
Taan	1994	4-94	99.33	100	99.33	IRS
	1995	4-95	94.25	100	94.25	IRS
	1996	4-96	93.38	100	93.38	IRS
Chungcheng first	1994	5-94	100	100	100	CRS
	1995	5-95	98.45	98.58	98.45	IRS
	1996	5-96	100	100	100	CRS
Chungcheng second	1994	6-94	100	100	100	CRS
	1995	6-95	100	100	100	IRS
	1996	6-96	82.85	83.35	99.40	IRS
Sungshan	1994	7-94	91.83	92.36	99.43	IRS
	1995	7-95	80.74	82.25	98.16	IRS
	1996	7-96	98.35	100	98.35	IRS
Shinyi	1994	8-94	77.51	67.45	96.83	IRS
	1995	8-95	71.71	74.30	96.51	IRS
	1996	8-96	79.80	84.99	93.89	IRS
Shihlin	1994	9-94	77.51	80.85	95.87	IRS
	1995	9-95	81.87	87.99	93.04	IRS
	1996	9-96	94.42	100	94.42	IRS
Peitou	1994	10-94	79.17	83.75	94.53	IRS
	1995	10-95	80.05	88.49	90.46	IRS
	1996	10-96	78.55	84.33	93.15	IRS
Wenshan first	1994	11-94	78.86	100	78.86	IRS
	1995	11-95	65.46	99.53	65.77	IRS
	1996	11-96	60.88	83.09	73.27	IRS
Wenshan second	1994	12-94	89.10	100	89.10	IRS
	1995	12-95	84.73	100	84.73	IRS
	1996	12-96	69.49	80.16	80.45	IRS
Nankang	1994	13-94	100	100	100	CRS
	1995	13-95	71.47	100	71.47	IRS
	1996	13-96	73.10	99.12	73.75	IRS
Neihu	1994	14-94	74.80	76.21	98.15	IRS
	1995	14-95	80.08	81.16	99.05	IRS
	1996	14-96	100	100	100	CRS
		Mean	86.97	92.61	93.83	

[a] Number of DMUs: $14 \times 3 = 42$.

From Table 4, we also observe that the average scale efficiency was 93.83. This suggests a further potential output improvement of 6.23% if it were possible for a police precinct to operate at constant returns to scale. Investigating the distribution of scale in Table 4 reveals that 10 DMUs already operate at the appropriate level: Chengcheng first Precinct (1994, 1996), Chengcheng second Precinct (1994, 1995), Chungshan Precinct (1994–1996), Nankang Precinct (1994), Neihu Precinct (1994), and Tatung Precinct (1994). On the other hand, 32 DMUs are experiencing increasing return to scale. This suggests that the latter precincts could improve performance if current operating output levels were increased.

Table 4 lends itself to a study of trends and the potential problems within the window. Consider, for instance, the 78.86 overall efficiency score shown for Wenshan first Precinct in 1994. This value differs considerably from the 65.46 (−16%) and 60.88 (−23%) efficiency scores from the 1995 and 1996 evaluations. Given that the relative efficiency ratings for Wenshan first Precinct are generally low and declining, further investigation should be considered. Neihu Precinct was found to have 74.80 overall efficiency in 1994. However, this value differs substantially from the 80.08 (+7%) and 100 (+34.80%) efficiency values found in the 1995 and 1996 evaluations, respectively. The overall efficiency ratings for Neihu Precinct exhibit an upward trend, especially in the latter part of the three-year study period and this, too, is potentially useful for evaluating its behavior. Similarly, one can analyze the trends and potential stability problems using technical and scale efficiency ratings obtained for these precincts.

Table 5 summarizes the results of Table 4 in what we believe is another useful way. Note, for example, that Wenshan first Precinct has the lowest overall mean efficiency score (68.40), yet it has a relatively high variance. Part of the latter may be due to the unusually low overall efficiency rating of 60.88 in the 1996 evaluation of this DMU. We would thus suggest that this DMU be set aside for further examination. On the other hand, low means tend to be accompanied by high

Table 5
Mean-variance analysis across windows[a]

Precinct	Overall efficiency			Technical efficiency		
	Mean	Variance	Group	Mean	Variance	Group
Tatung	93.75	32.088	IV	93.84	20.734	IV
Wanhua	92.03	58.074	IV	93.35	32.588	IV
Chungshan	100	0	I	0	0	I
Taan	95.65	10.328	IV	0	0	I
Chungcheng first	99.48	0.801	I	99.52	0.448	I
Chungcheng second	94.28	65.361	IV	94.45	61.605	IV
Sungshan	90.31	79.268	IV	91.25	52.543	IV
Shinyi	76.34	17.389	IV	75.58	33.408	IV
Shinlin	84.60	77.077	IV	89.61	27.117	IV
Peitou	79.26	0.568	I	85.52	4.457	III
Wenshan first	68.40	87.303	IV	94.21	61.827	IV
Wenshan second	81.11	105.984	IV	93.39	87.472	IV
Nankang	81.52	256.705	IV	99.71	0.172	I
Neihu	84.96	176.621	IV	85.79	105.047	IV

[a] Group: (I) very low σ^2; (II) low σ^2; (III) medium σ^2; (IV) high σ^2.

variances in Table 5, with the possible exception of Peitou Precinct. While it appears in the very low variance group (I), it was found to have an overall efficiency rating of 79.17 in 1994. This value does not differ very much from the 80.08 (+1%) and 78.55 (−0.7%) efficiency values found in the 1995 and 1996 evaluations (see Table 4); this, too, should be investigated in more detail.

Chengcheng second Precinct, Wenshan first, and Wenshan second Precinct were found to have high mean technical efficiency values (94.45, 94.21 and 93.39, respectively). Each of these precincts also has a high variance in its overall efficiency ratings. Perhaps the high variance in their efficiency ratings may be due to the low ratings of 83.35 for Chengcheng second Precinct, 83.09 for Wenshan first Precinct, and 80.16 for Wenshan second in the 1996 evaluation of these DMUs.

The remaining empirical results are focused on technical efficiency as presented in the following sections.

5.2. Peer references

An inspection was next made of how frequently each efficient precinct was used as a comparator of 'efficient peer' for inefficient precincts. Here, we sought to identify an exemplar of good performance according to the number of times efficient precincts appeared in the reference set. The reference sets and their frequencies for the 42 DMUs are given in Table 6. The most frequent efficient peers were found to be Taan Precinct (1994), Tatung Precinct (1994), Chungshan Precinct (1995) and Chungcheng second Precinct (1995). These four thus have the most usual mixes of crime level, officer strength, and clear ups, i.e., they were 'good performers' in terms of all their input–output levels.

In order to gain a better insight into the performance of precincts, we looked at the correlation between inputs and their technical efficiency scores. Three inputs were positively associated with efficiency scores. In general, higher manpower levels were weakly associated with higher efficiency ratings. This finding is consistent with Thanassoulis [8]. The lowest correlation coefficients found were: 0.04 between police officer levels and efficiency scores, 0.11 between offence levels and efficiency scores, and 0.14 between burglary levels and efficiency scores, and between other crime levels and efficiency scores.

5.3. Input and output contributions

A good view of the performance of each inefficient precinct can be gained when its input/output contributions are contrasted with those of its efficient peer reference unit, as identified in Table 6. This contribution can be measured in terms of how much input/output of a DMU has been used in determining efficiency. The values are thus 'normalized' to show a percentage of the overall input and output contribution, and are obtained through the following computational procedure:

Step 1: For the efficient unit(s), calculate input/output variables times lambda for each variable;

Step 2: Take the Step 1 result for each variable and divide it by the largest value for each variable for the inefficient unit; and

Step 3: Multiply by 100 to get the percentage value for the inefficient unit.

Table 7 shows the input/output contributions of the 42 DMUs. One may then make comparisons of an inefficient unit and its reference set using tables such as Table 8, below.

Table 6
Reference sets for the 42 DMUs

DMU Code	BCC model Reference set	Frequency
1-94		13
2-94		2
3-94		5
4-94		12
5-94		9
6-94		9
7-94	1-94 3-94 4-94 6-94 5-96	
8-94	1-94 3-94 4-94 5-94 6-94 6-95 5-96	
9-94	1-94 4-94 5-94 5-96	
10-94	1-94 2-94 4-94 5-94 6-94	
11-94		3
12-94		0
13-94		6
14-94	1-94 3-94 4-94 5-94 6-94 5-96	
1-95	1-94 4-94 5-94	
2-95	1-94 2-94 3-95	
3-95		10
4-95		4
5-95	1-94 4-94 5-94 6-94 6-95 5-96	
6-95		11
7-95	1-94 6-94 13-94 3-95	
8-95	4-94 3-95 6-95 4-96 14-96	
9-95	4-94 3-95 4-95 6-95 9-96	
10-95	4-94 3-95 6-95 9-96	
11-95	5-94 11-94 13-95	
12-95		4
13-95		2
14-95	3-95 4-95 6-95 9-96	
1-96	1-94 4-94 6-94 3-95	
2-96	1-94 3-94 3-95 4-95 6-95	
3-96		0
4-96		1
5-96		6
6-96	5-94 6-94 6-95 12-95	
7-96		0
8-96	3-94 3-95 4-95 6-95	
9-96		4
10-96	4-94 6-95 9-96	
11-96	5-94 13-94 12-95 5-96	
12-96	1-94 6-94 13-94 3-95 6-95	
13-96	1-94 13-94 12-95 13-95	
14-94		1

Table 7
Input/output contributions of the 42 DMUs

DMU code	Input				Output		
	x_1	x_2	x_3	x_4	y_1	y_2	y_3
1-94	99.9999	0	3.3470	7.2847	4.5196	5.125E−5	99.9999
2-94	0.0001	99.9997	5.6208	0.0001	91.1282	3.8718	6.7180
3-94	0.0001	99.9996	6.2958	0.0001	96.4840	3.5159	0.0001
4-94	0.0003	9.3033	0.0001	99.9995	7.4019	5.1667	99.9999
5-94	0.0001	38.0186	1.7955	61.9813	3.4777	99.9999	3.3613
6-94	56.7436	43.2564	4.9217	6.7839	99.9999	2.1667	2.9739
7-94	52.2030	2.4716	16.2581	31.5389	54.5331	3.0833	45.4669
8-94	30.4285	7.6588	3.3888	61.9126	61.0602	38.9398	2.7218
9-94	8.0229	2.5513	60.7014	39.2985	21.1151	3.0417	78.8849
10-94	9.2095	55.1481	15.8512	29.0006	55.9951	44.0049	4.0710
11-94	7.6974	9.9788	99.9999	2.7172	1.2179	7.5E−6	99.9999
12-94	8.6310	1.5801	99.9999	3.9116	1.7185	9.5933	99.9999
13-94	83.8689	5.4309	3.8239	16.1309	99.999	1.1667	1.8861
14-94	7.7502	14.9812	69.7978	7.4707	57.8862	2.375E−5	42.1138
1-95	18.1083	2.2337	2.5980	81.8916	3.8160	4.0833	99.9999
2-95	0.0001	51.0848	9.3017	48.9150	6.2652	99.9999	6.4286
3-95	0.0001	62.1549	0.0001	37.8449	0.0001	99.9998	9.5191
4-95	0.0001	0.0001	9.8287	99.9996	8.0650	87.1649	12.8350
5-95	49.6919	3.1307	7.5104	42.7977	34.2941	29.2395	36.4664
6-95	51.4329	2.3256	9.0627	39.5043	36.7495	35.2839	27.9666
7-95	78.1807	4.2672	2.831	21.8192	48.7603	3.75E−5	51.2397
8-95	30.4285	7.6588	3.3889	61.9126	61.0602	38.9398	2.7218
9-95	22.2931	3.7119	6.7665	73.9950	4.8714	67.8929	32.1071
10-95	0.0001	26.7088	4.8480	73.2910	2.9499	92.1030	7.8969
11-95	5.3593	2.2973	2.0817	94.6407	1.3938	99.9999	1.5826
12-95	59.5797	9.1731	40.4203	8.0815	2.7605	99.9999	1.8954
13-95	99.9999	2.6195	2.2619	2.6821	1.8268	99.9999	1.8207
14-95	29.9300	4.3224	3.2555	70.0700	3.5318	72.6727	27.3272
1-96	45.5665	2.3731	2.8338	54.4334	32.8386	4.1667	67.1613
2-96	0.0001	5.1646	52.4076	42.4277	6.2652	97.8792	2.1208
3-96	23.3811	25.3689	26.2617	24.9884	9.1339	99.9998	9.4678
4-96	0.0007	0.0006	0.0004	99.9982	99.9999	6.0833	7.1755
5-96	0.0002	0.0001	99.9995	0.0001	99.9999	3.2917	3.5434
6-96	37.3954	6.8167	4.7037	62.6046	48.0203	54.9797	2.3950
7-96	82.0964	6.7776	17.9035	4.3570	73.0623	22.4637	4.4739
8-96	18.8182	7.6828	50.3659	30.8159	4.5467	99.9999	2.8151
9-96	0.0001	0.0001	0.0001	99.9996	5.4398	99.9999	4..2110
10-96	9.3364	4.6075	4.0253	99.9998	3.6671	75.2009	24.7490
11-96	71.3891	6.3593	28.4878	0.1231	1.5291	99.9999	1.6713
12-96	81.5858	1.0332	6.9762	18.4142	49.8488	18.4565	31.6947
13-96	99.9999	6.0939	3.6426	5.9281	21.7401	36.7814	41.4785
14-94	99.9999	4.7737	3.1604	2.8161	99.9999	3.6666	2.9692

Table 8 relates to inefficient DMU8-94: Shinyi Precinct (1994). The column headed 'DMU8-94' shows its 'normalized' input/output contributions. The input/output contributions under DMU1-94: Tatung Precinct (1994), are its normalized input/output contributions so that one of its input contributions (police officers) is higher than that of Shinyi Precinct (1994) while none of the rest of its input contributions is higher than the corresponding contribution of Shinyi Precinct (1994). The input–output contributions of the rest of the efficient peers have been normalized in a similar manner. This makes it straightforward to compare Shinyi Precinct (1994) with its peers as we can now focus solely on output contributions.

If Shinyi Precinct (1994) is deemed to have equivalent performance to that of its efficient peers, its output contributions must be at least as good as those of its peers. In fact, Shinyi Precinct (1994) has better output contribution (burglary clear ups) than Chungcheng first Precinct (1994), Chungcheng second Precinct (1996), Taan Precinct (1994), and Tatung Precinct (1994). It also has better output contribution (offence clear ups) than its peer references, with the exception of Chungcheng first Precinct (1994). Finally, it has better output contribution (other crime clear ups) than does Chungshan Precinct (1994), Chungcheng first Precinct (1994, 1996), and Chungcheng second Precinct (1996). Clearly, tables such as Table 8 can be used to review the performance of any other inefficient precincts.

5.4. Slack analysis

In order to find information indicating by how much and in what areas an inefficient unit needs to improve, a non-zero slack analysis was used. Such analysis can identify marginal contributions in efficiency ratings with either an additional increase in specific output amounts or decrease in specific input amounts. Table 9 represents the results of our slack analysis.

Among the input measures, the number of burglaries recorded had the greatest number of non-zero slacks, 14, while the highest number of non-zero slacks for output measures was 32. Holding the level of police services constant, on average, six DMUs could reduce the number of police officers by 26.56 officers; 14 DMUs could reduce the number of burglaries by 239.04; 13 DMUs

Table 8
Efficient peers for DMU8-94 (efficiency 67.45)

Inefficient unit	Efficient peers							
	DMU8-94	DMU1-94	DMU3-94	DMU4-94	DMU5-94	DMU6-94	DMU6-95	DMU5-96
Inputs								
x_1	44.0112	99.9999	0.0001	0.0003	0.0001	56.7436	51.4329	0.0002
x_2	10.6759	0	99.9996	9.3033	38.0186	43.2564	2.3256	0.0001
x_3	21.4354	3.3470	6.2958	0.0001	1.7955	4.9217	9.0627	99.9995
x_4	23.8775	7.2847	0.0001	99.9995	61.9813	6.7839	39.5043	0.0001
Outputs								
y_1	50.4193	4.5196	96.4840	7.4019	3.4777	99.9999	36.7495	99.9999
y_2	38.2768	5.125E−5	3.5159	5.1667	99.9999	2.1667	35.2839	3.2917
y_3	11.3039	99.9999	0.0001	99.9999	3.3613	2.9739	27.9666	3.5434

Table 9
Slacks for each input and output for the inefficient DMUs

DMU code	Inputs				Outputs		
	x_1	x_2	x_3	x_4	y_1	y_2	y_3
7-94	0	20.75	0	0	30.51	22.84	85.26
8-94	0	0	0	0	118.73	29.44	320.46
9-94	23.26	94.34	0	0	77.2	39.62	266.64
10-94	2.3	0	0	0	64.8	14.75	228.79
14-94	0	0	0	0	84.29	25.15	231.02
1-95	0	285.81	25.67	0	45.55	17.16	111.94
2-95	2.85	0	36.21	0	79.92	23.98	354.31
5-95	0	357.62	0	0	4.37	1.25	11.92
7-95	0	914.09	33.22	0	72.73	34.26	249.04
8-95	0	0	12.5	0	108.27	27.67	247.23
9-95	0	0	98.51	0	91.27	16.25	133.53
10-95	43.95	0	12.58	0	154.54	13.27	96.82
11-95	0	41.02	7.91	0	53.51	0.21	118.44
14-95	0	214.57	15.56	0	96.38	21.59	146.28
1-96	0	252.13	16.52	0	38.28	23.13	172.4
2-96	11.34	0	0	0	103.69	10.89	110.48
6-96	0	198.72	3.75	0	50.92	10.38	147.76
8-96	0	151.4	0	0	59.36	18.2	328.35
10-96	75.66	233.23	40.28	0	55.7	16.36	106.87
11-96	0	139.82	0	0	135.47	7.53	140.11
12-96	0	249.53	22.62	0	48.51	8.66	98.76
13-96	0	193.62	11.15	74	1.65	0.33	3.65
Number of DMUs with slacks	6	14	13	1	32	32	32
Mean	26.56	239.04	25.88	74	49.24	11.98	115.94

could reduce the number of offences by 25.88; and one DMU could reduce the number of other crimes by 74. Further, 32 DMUs could increase the number of burglary clear ups by 49.24, the number of offence clear ups by 11.98, and the number of other crime clear ups by 115.94. Those having zero slack, of course, required no such addition to achieve their value if efficient. These estimated reductions in inputs would not, in themselves, suffice. They would also need to be accompanied by the estimated increases in outputs if an inefficient precinct were to achieve 100% efficiency.

Solution of our DEA models yielded target input and output levels that would render inefficient precincts efficient, if not already so (see [1]). Information on such target levels is given in Table 10. It can be used to provide the Police Department with important suggestions for improving the performance of their inefficient units.

The TARGET column shows the levels of inputs and outputs that an inefficient precinct should be using or producing in order to be efficient, while the POTENTIAL IMPROVEMENT column shows how much, in percentage terms, an inefficient precinct's use of inputs or production of

Table 10
Targets and potential improvements for the inefficient DMUs

DMU code	Target							Potential improvement						
	x_1	x_2	x_3	x_4	y_1	y_2	y_3	x_1	x_2	x_3	x_4	y_1	y_2	y_3
7-94	331	548.25	84	926	399.51	96.84	1116.26	0	−3.65	0	0	8.27	30.86	8.27
8-94	342	409	79	691	364.73	90.44	984.46	0	0	0	0	48.26	48.26	48.26
9-94	382.74	509.66	105	986	403.20	112.62	1392.64	−5.73	−15.62	0	0	23.68	54.27	23.68
10-94	368.70	383	93	738	398.80	90.75	1100.79	−0.62	0	0	0	19.4	19.4	26.24
14-94	308	316	76	720	354.29	82.15	971.02	0	0	0	0	31.22	44.12	31.22
1-95	327	306.19	101.33	1059	327.55	115.16	1472.94	0	−48.28	−20.22	0	16.15	17.51	8.22
2-95	415.15	1075	249.79	1693	542.92	171.98	1731.31	−0.68	0	−12.66	0	17.26	16.20	25.73
5-95	291.00	365.38	70.00	590	307.37	88.25	838.92	0	−49.46	0	0	1.44	1.44	1.44
7-95	331	730.91	171.78	1191	409.73	124.56	1403.04	0	−55.57	−16.21	0	21.58	38.40	21.58
8-95	342	1080	135.50	740	421.27	107.67	830.23	0	0	−8.45	0	34.59	34.59	42.41
9-95	406	1337	179.49	935	451.27	135.25	1111.53	0	0	−35.44	0	25.35	13.65	13.65
10-95	327.05	748	128.42	716	372.54	115.27	840.82	−11.85	0	−8.92	0	70.898	13.01	13.01
11-95	216	317.98	52.09	359	156.51	44.21	457.44	0	−11.43	−13.18	0	51.95	0.47	34.94
14-95	308	800.43	125.44	691	357.38	114.59	776.28	0	−21.14	−11.04	0	36.93	23.22	23.22
1-96	334	369.87	120.48	1180	352.28	123.13	1586.40	0	−40.53	−12.05	0	12.19	23.13	12.19
2-96	415.66	1310	286	1693	566.69	180.89	1834.48	−2.66	0	0	0	22.40	6.41	6.41
6-96	277	241.28	52.25	400	305.92	62.38	660.76	0	−45.16	−6.70	0	19.97	19.97	28.80
8-96	350	1061.6	133	813	395.36	121.20	931.35	0	−12.48	0	0	17.67	17.67	54.45
10-96	30.34	641.77	100.72	570	326.70	104.36	681.87	−199.6	−26.66	−28.57	0	20.55	18.59	18.59
11-96	221.00	363.18	36	428	248.47	44.53	498.11	0	−27.80	0	0	119.88	20.35	39.14
12-96	214	288.47	44.38	432	244.51	43.66	497.76	0	−46.38	−33.75	0	24.75	24.75	24.75
13-96	195	323.38	45.85	380	186.65	37.33	413.65	0	−37.45	−19.57	−16.3	0.89	0.89	0.89

output needs to change in order for it to be efficient. For example, DMU8-94: Shinyi Precinct in the 1994 evaluation could increase the number of burglary clear ups from 246 to 334 (an addition of 48.26%), the number of offence clear ups from 73 to 90.44 (an addition of 48.26%), and the number of other crime clear ups from 664 to 984.46 (an addition of 48.26%), in order to become as efficient as its peer references.

Care is needed in interpreting target crime levels. One should be aware that crime levels are, for the most part, beyond the control of any police precincts. It can only be influenced by crime prevention measures while crime will be deterred by high detection levels. Crime target levels indicate reductions in crime levels that must take place before corresponding reductions in the clear up level are justifiable if a police precinct is to be efficient.

5.5. Multiple regression analysis

As discussed earlier, regression was used in the second-stage analysis to explain the variation in DEA technical efficiency scores from the first stage. Based on previous police reports (i.e. [12–14]), we identified several environmental variables, or non-controllable inputs, that may affect the efficiency of a police precinct. Police observe that most offenders are young people aged 15–29 years. A higher population of young people in a police jurisdiction is likely to respond to more incidents compared to a lower population. Further, a precinct with a higher population of residents in its jurisdiction is likely to respond to more crime compared to a similar precinct having a lower population. A precinct covering a larger jurisdiction area requires police officers above the level of resources justified by the services they provide to the community. A precinct with a wider jurisdiction is likely to respond to more crimes compared to a similar precinct having a smaller jurisdiction due to lack of sufficient staff. Finally, a police precinct located in a downtown area is likely to respond to more crime compared to a similar precinct located in a suburban area.

The jurisdiction areas of police precincts studied here, their populations, and populations of young people were derived from 1994–1996 statistical data reported in Refs. [12–14]. A dummy variable was used to specify the location of a given police precinct, where a value of 1.0 indicates that the precinct is located downtown and 0.0 if it is located in the suburbs. Precincts with a higher population of young people or a higher population of residents are expected to be more efficient than those with lower populations having these socioeconomic conditions since they respond to more crime (i.e., they have less idle time). Nevertheless, we expect downtown police precincts to have higher measured outputs because they are generally more closely supervised than their suburban counterparts. Precincts with larger jurisdictions are expected to be relatively inefficient compared to those with smaller jurisdiction because they require more inputs to provide an effective service.

To determine whether environmental factors affect the efficiency of police precincts, technical efficiency scores were regressed against the location, the jurisdiction area, the population, and the population of young people that live in a police jurisdiction. The regression results of Table 11 explain about 6% of the variation in technical efficiency scores and none of the coefficients of the explanatory variables are significant at $p = 0.05$. Consequently, we conclude that the efficiency of the police precincts studied is not influenced by these environmental variables. Our findings are consistent with those of Carrington et al. [9].

Table 11
Results of multiple regression[a]

Variable	Regression coefficient	Standard error	T-Ratio	Probability $>\|t\|$
LOC	−3.0869	2.6307	−1.17	0.2481
JURA	−0.0384	0.1356	−0.28	0.7784
RPOU	9.2E−6	3.1E−5	0.30	0.7684
YPOU	−3E−7	2.1E−5	−0.12	0.9048
CONSTANT	89.0588			
R^2	0.0614			

[a] LOC: location of a police precinct; JURA: jurisdiction area of a police precinct; RPOU: population of residents who live in a district area; YPOU: population of young people who live in a district area.

6. Conclusions

This paper has given an account of a DEA application to the assessment of policing performance in Taipei city, Taiwan. Chungshan Precinct was rated as the most efficient in terms of overall, technical, and scale efficiencies for the years 1994–1996 using police statistical data.

We have shown that police precincts can be investigated in terms of their relative efficiency. The overall performance of precincts was assessed by setting their clear up levels against their crime and manpower levels. This identified potentially weak and strong precincts on performance, their efficient peers, and the levels of clear ups that would render inefficient precincts efficient. In particular, Chengcheng first Precinct (1994, 1996), Chengcheng second Precinct (1994, 1995), Chungshan Precinct (1994–1996), Nankang Precinct (1994), Neihu Precinct (1994), and Tatung Precinct (1994) already operate at appropriate levels. The other precincts are experiencing increasing returns to scale and could improve their output levels to be efficient. There is a weak suggestion that higher manpower levels were associated with higher performance efficiency. Nevertheless, our analysis indicated that differences in operating environments and socioeconomic factors do not have a significant influence on the efficiency of police precincts.

A few notes of caution are in order here. Our study is in terms of highly aggregated measures of outputs and inputs. There are important qualitative dimensions of outputs that were not taken into account; for example, the quality of police work and police officers. It would be desirable to treat these outputs explicitly in the models used here. Our basic methodology would remain valid, however.

Finally, it is important to note that our findings are but indicators of relative efficiency (or inefficiency), which are a means to an end—efficient operations—and not an end in themselves. As such, the information serves as a guide to the Taipei Police Department for additional investigation into enhancing their precincts' performance efficiency.

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