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Predicting bank performance with financial forecasts: A case of Taiwan commercial banks

Chiang Kao [a,*], Shiang-Tai Liu [b]

[a] *Department of Industrial and Information Management, National Cheng Kung University, Tainan 701, Taiwan, ROC*
[b] *Graduate School of Business and Management, Vanung University, Chung-Li 320, Taiwan, ROC*

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Abstract

Data envelopment analysis (DEA) has been used as a tool for evaluating past accomplishments in the banking industry. However, due to a time lag, the results usually arrive too late for the evaluated banking institutions to react timely. This paper makes advanced predictions of the performances of 24 commercial banks in Taiwan based on their financial forecasts. The forecasts based on uncertain financial data are represented in ranges, instead of as single values. A DEA model for interval data is formulated to predict the efficiency. The predictions of the efficiency scores are also presented as ranges. We found that all the efficiency scores calculated from the data contained in the financial statements published afterwards fall within the corresponding predicted ranges of the efficiency scores which we had calculated from the financial forecasts. The results also show that even the bad performances of the two banks taken over by the Financial Restructuring Fund of Taiwan could actually be predicted in advance using this study.

JEL classification: C67; G21
Keywords: Data envelopment analysis; Imprecise data; Performance; Banking industry

* Corresponding author. Tel.: +886-6-275-3396; fax: +886-6-236-2162.
E-mail addresses: ckao@mail.ncku.edu.tw (C. Kao), stliu@cc.vit.edu.tw (S.-T. Liu).

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1. Introduction

Over the past 30 years Taiwan has achieved high economic development while maintaining mild inflation and low unemployment. At the same time, the structure of its financial system has changed from a controlled system into a liberalized one. The financial system has played a key role in the process of Taiwan's economic development (Yu, 1999). The widespread relaxation of the financial system has resulted in a more efficient financial market and enhanced financial technology. On the down side, however, the keener competition in financial markets has had a huge impact on various kinds of operating risk encountered by financial institutions. Since the Southeast Asian financial crisis of July 1997, most of the countries in that region have suffered from its impact. One of the main factors in that financial crisis was excessive risk-taking, especially after the finance liberalization in Southeast Asia. The major cause leading to excessive risk-taking is the inadequate regulatory system (Mishkin, 1999). An efficient financial system must have a sound regulatory system, not only to help financial institutions achieve expected development but also to prevent them from relying on risk-taking.

The most effective way to enforce financial rules and regulations in the financial supervisory system is to conduct financial examinations. In Taiwan, the principal government agencies responsible for the supervision of financial institutions are the Central Bank of China, the Ministry of Finance, and the Central Deposit Insurance Corporation. These three bank regulators use the CAMELS rating system, which consists of six categories, including Capital adequacy, Asset quality, Management, Earnings, Liquidity, and Sensitivity to market risk, to evaluate the banks in Taiwan. This system relies on various financial ratios obtained from periodic reports of the entities under their jurisdiction. The ratios are also aggregated into performance indices based on various weighting or scoring schemes. The aggregation of the ratios can be a complicated process involving subjective judgment. The changing economic conditions have made such aggregations even more difficult, increasing the need for a more reliable way to express a bank's financial condition.

Data envelopment analysis (DEA) for efficiency measurement has seen extensive applications in the study of commercial banks (Bauer et al., 1998; Berger and DeYoung, 1997; Berger and Humphrey, 1997; Bhattacharyya et al., 1997; Elyasiani and Mehdian, 1990; Miller and Noulas, 1996; Rezvanian and Mehdian, 2002; Sherman and Ladino, 1995; Yeh, 1996; Yue, 1992). Several authors have also proposed that DEA efficiency measures be used as the evaluative information for the management component of CAMELS (Barr et al., 1993, 1994; Brockett et al., 1997; Siems, 1992; Siems and Barr, 1998). In most studies the DEA approach has been used as a tool for evaluating accomplishments in the past. The results highlight the status of the operational performance and are helpful for planning future activities for improving the performance. However, this ex post facto evaluation might be a little late for an unsuccessful unit to find its weaknesses and make the appropriate amendments. In this paper we predict the performance of the commercial banks in Taiwan based on the forecasted financial data via DEA. The results are regarded as forward-looking information, which can be used for planning management activities in advance to enhance the operational performance. Since the input–output data are the financial forecasts of the banks, considerable uncertainty is involved. We thus develop a solution method to solve the problem of imprecise data encountered in measuring the relative efficiency.

The rest of this paper is organized as follows: first we discuss the input and output factors used to measure the efficiency of commercial banks, then we develop a solution method to calculate the relative efficiency of the banks with imprecise data under the DEA framework. Next, the case of Taiwan's commercial banks is adopted for illustration, and finally, the results are discussed and some conclusions drawn from the discussion.

2. Inputs and outputs

Selecting proper inputs and outputs is probably the most important task in successfully applying DEA to measure the relative efficiency of the decision making units (DMUs) since they determine the context for comparison. In the banking industry, there are different viewpoints regarding inputs and outputs. According to the Banking Law of the Republic of China on Taiwan, the primary functions of commercial banks are to receive checking account deposits and to extend short-term credit. The regular operations include servicing checking accounts, demands, and time deposits; extending short-term and medium-term loans; engaging in domestic and foreign remittances and guaranty business; and underwriting government bonds, treasury bills, and corporate bonds. The detailed operations in which a commercial bank may engage can be found in the Banking Law of Taiwan (2000).

From looking at the operation contents of the commercial banks in Taiwan, one soon realizes that the availability of funds and the costs of deposits are not the major consideration of banks. The emphasis of bank management is to make proper decisions. Instead of offering competitive interest rates on saving accounts to attract stable deposits for credit applications, bank managers focus their attention on credit analysis to determine a borrower's ability to repay loans, along with collateral evaluation and documentation screening to protect the bank's financial profits and to be sure deposit payments are duly made. Another task is to adjust the interest rates paid on deposits and the interest rates charged to loans to secure more profit. In other words, the role played by the banks of Taiwan is primarily to mediate funds between depositors and borrowers. In this sense, the commercial banks in Taiwan can be regarded as financial intermediaries, whose main business is to borrow funds from depositors to lend to others (Yeh, 1996; Yue, 1992).

Based on the inter-mediation concept and the empirical study of Yeh (1996), three inputs are considered in evaluating a bank's performance: total deposits, interest expenses, and non-interest expenses. Total deposits are composed of checking accounts and time deposits. Interest expenses include expenses for deposits and other borrowed money. Non-interest expenses include service charges and commissions, expenses of general management affairs, salaries, and other expenses. These inputs represent the costs of labor, administration, equipment and funds purchased for bank operations, and the source of loanable funds for investment (Yeh, 1996).

Regarding the outputs in assessing bank performance, there are also three factors, viz., total loans, interest income, and non-interest income. Total loans consist of short-term and medium-term loans. Interest income includes interest on loans, income from government bonds and corporate bonds, and interest and dividend income on securities. Non-interest income includes service charges on loans and transactions, income from renting and fiduciary activities, commissions, and other operating income. These outputs represent bank revenue and the major profit-making business activities (Yeh, 1996). One thing to be noted is that according to the Banking Law of Taiwan, the total loans extended by a bank may not exceed its balance of total deposits. This makes the performance evaluation a little more complicated.

In Taiwan there are 48 commercial banks, with total assets of 422.76 billion US dollars. The average is 8.8 billion for each bank. Of the 48 banks, 30 (62.5%) are on the security list of Taiwan Stock Exchange Corporation (TSEC). Their total assets are 348.9 billion US dollars, which accounts for 82.53% of the total assets of the 48 banks, with an average of 11.63 billion. The total assets of the other 18 banks are 4.1 billion. These 30 commercial banks are the target of this study. The financial data for inputs and outputs are the source for measuring their relative efficiencies. In March 2000, questionnaires were sent to the general managers of the 30 banks to ask for their forecasts of the financial data. We asked that the forecasts for the three inputs and three outputs be expressed in intervals rather than single values due to their uncertain nature. Of the 30 banks, 24 provided all the data required for our analysis. Those 24 banks were also visited to make sure that they had provided the data we wanted. The banks that did not respond are all relatively small. The largest one has total assets of 9.43 billion dollars which is smaller than the average of the 30 listed banks–11.63 billion. Their total assets are 49.3 billion dollars, accounting for 14.13% of the total assets of the 30 listed banks. The average is 8.22 billion as opposed to the 12.48 billion average of the 24 banks which responded. Table 1 shows the input and output data of the 24 banks. The monetary values are in Taiwan dollars, where 1 US dollar is approximately equal to 35 Taiwan dollars.

According to the regulations of Taiwan's Securities and Futures Commission, the commercial banks must publish their financial forecasts for the coming calendar year. The publication and reporting of the information regarding the financial forecast should also be submitted to the Securities and Futures Institute (SFI) for public inspection. This publication of financial information should be completed by the end of April. For this reason, we sent our questionnaires to ask the banks financial forecasts for the following calendar year in March 2000, and received their responses in April. Every bank has the forecasts available at the beginning of the year. They could actually have provided the forecasts earlier. However, it is obvious that the earlier the forecasts are made the less accurate they will be. Nonetheless, the methodology of this paper is still applicable. The regulators can decide the time they want to collect the forecasts. In Section 3, we shall develop a solution procedure for predicting bank performances using interval financial data.

Table 1
Interval forecasts of financial data, in million Taiwan dollars, for the 24 commercial banks in Taiwan

Bank		Total deposits	Interest expenses	Non-interest expenses	Total loans	Interest income	Non-interest income	Efficiency score
1	L	788670.598	40241.939	11811.938	724380.137	60822.392	7094.716	0.8630
	U	840589.352	43683.964	12022.587	773314.721	66231.622	7623.200	1.0
2	L	926135.923	42863.302	15496.878	786268.246	66067.139	12826.685	0.8034
	U	1014339.344	49421.622	17952.668	850782.563	72605.032	14022.957	1.0
3	L	895985.403	40469.853	13030.998	770236.241	57395.587	11691.722	0.8320
	U	989805.864	43436.229	13986.150	861676.051	64209.395	13079.723	1.0
4	L	458981.787	29869.433	6267.727	418079.491	44354.534	5663.309	0.8893
	U	516654.891	32997.122	6924.034	467712.458	49620.152	6335.638	1.0
5	L	235351.052	7881.369	2820.190	169336.032	11427.471	1618.144	0.8037
	U	259995.141	8706.643	3115.498	189439.027	12784.101	1810.244	1.0
6	L	256277.540	8499.210	1163.290	200432.663	11234.126	2845.686	1.0
	U	283112.884	9389.179	1285.101	224227.342	12567.803	3183.516	1.0
7	L	108792.763	5421.990	1405.508	80058.742	7848.875	302.146	0.7279
	U	120184.676	5791.026	1596.834	89563.042	8612.776	338.016	1.0
8	L	78795.804	4052.711	2488.023	47904.990	4975.084	249.434	0.5956
	U	85261.100	4430.684	2720.066	53079.753	5459.290	279.046	0.8782
9	L	383560.820	27531.866	5352.499	325799.311	35344.225	5393.143	0.8451
	U	411675.225	29694.054	5744.829	353146.196	3831.942	5963.517	1.0
10	L	507635.274	22708.680	3727.914	402910.427	37609.645	3298.457	0.8878
	U	560790.800	25086.553	4118.272	441709.209	42074.533	3543.683	1.0
11	L	166251.006	8518.755	3621.040	147175.582	11443.133	1671.398	0.8148
	U	182253.777	8960.141	3886.457	167355.327	12593.500	1869.820	1.0
12	L	176709.762	8324.757	1554.942	158536.003	11591.017	710.441	0.8476
	U	194858.332	8804.193	1644.494	177494.947	12967.063	794.782	1.0
13	L	432487.877	21002.182	2693.838	349537.634	29012.385	4799.480	0.8150
	U	477774.566	23201.364	2975.916	391033.546	32456.636	5369.258	1.0
14	L	717622.843	32432.931	5207.240	591874.449	45500.257	3017.951	0.8125
	U	770223.470	35154.161	5577.298	662139.758	50901.891	3376.232	1.0
15	L	101281.254	5491.093	4927.333	78813.646	7421.864	578.585	0.7150
	U	111886.621	6066.077	5443.284	87607.243	8302.962	647.272	1.0
16	L	126969.320	7023.181	3063.381	122170.193	9147.275	1698.281	0.8628
	U	141594.059	7758.592	3384.154	136673.820	10233.208	1899.895	1.0
17	L	145850.899	7933.351	5981.423	127122.118	12139.733	757.213	0.8016
	U	164181.887	8573.004	6607.750	144379.110	13437.207	8487.107	1.0
18	L	143347.258	8101.257	2799.391	126680.923	11828.337	2366.530	0.8280
	U	165099.735	8949.557	2904.323	144429.801	13232.557	2647.476	1.0
19	L	190173.529	9307.438	661.977	145200.476	13106.068	2027.188	1.0
	U	210086.987	10282.038	731.294	162438.180	14661.976	2267.849	1.0
20	L	216899.750	9514.108	1910.872	149165.081	12403.453	4760.565	1.0
	U	239611.766	10510.350	2110.963	166873.449	13875.948	5016.701	1.0
21	L	131203.426	6496.850	3852.749	101543.039	8989.748	1593.302	0.7449
	U	141507.360	7041.088	4119.012	108383.652	9644.386	1718.138	1.0
22	L	214511.844	10666.968	4651.894	171767.407	19395.850	3022.838	0.9472
	U	239220.015	11895.624	5187.714	194236.441	21933.037	3418.258	1.0
23	L	155200.082	9242.283	14248.464	91728.198	10657.757	1038.968	0.5987
	U	167934.447	10000.625	15577.337	105261.867	12003.138	1190.318	0.9147
24	L	153476.455	7816.278	1619.780	144453.154	11601.726	918.045	0.8709
	U	166608.130	8307.353	1721.547	157371.729	12320.208	969.975	1.0

L: lower bound, U: upper bound.

3. The solution procedure

Since the pioneer work of Charnes et al. (1978), DEA has been widely applied to measuring the relative efficiencies of a set of DMUs utilizing the same inputs to produce the same outputs. One form of their model for measuring the efficiency of DMU r is

$$\begin{aligned} E_r = \max \quad & \sum_{k=1}^{t} u_k Y_{rk} \\ \text{s.t.} \quad & \sum_{j=1}^{s} v_j X_{rj} = 1, \\ & \sum_{k=1}^{t} u_k Y_{ik} - \sum_{j=1}^{s} v_j X_{ij} \leqslant 0, \quad i = 1, \ldots, n, \\ & u_k, v_j \geqslant \varepsilon > 0, \quad k = 1, \ldots, t, \ j = 1, \ldots, s, \end{aligned} \tag{1}$$

where X_{ij} and Y_{ik} represent the jth input and kth output, respectively, of the ith DMU, and $\varepsilon > 0$ is a small non-Archimedean quantity (Charnes et al., 1979; Charnes and Cooper, 1984). In this model all observations must be precise. However, the data used for all inputs and outputs in this study are imprecise, lying in the ranges of $[X_{ij}^{\mathrm{L}}, X_{ij}^{\mathrm{U}}]$ and $[Y_{ik}^{\mathrm{L}}, Y_{ik}^{\mathrm{U}}]$, repsectively. We need to modify Model (1) to make it applicable to interval data.

Let $\widehat{X}_{ij} = [X_{ij}^{\mathrm{L}}, X_{ij}^{\mathrm{U}}]$ and $\widehat{Y}_{ik} = [Y_{ik}^{\mathrm{L}}, Y_{ik}^{\mathrm{U}}]$ denote the interval counterparts of X_{ij} and Y_{ik}, respectively. Specifically, $\widehat{X}_{i1}$, $\widehat{X}_{i2}$, and $\widehat{X}_{i3}$ represent total deposits, interest expenses, and non-interest expenses of the ith DMU, respectively, and $\widehat{Y}_{i1}$, $\widehat{Y}_{i2}$, and $\widehat{Y}_{i3}$ represent total loans, interest income, and non-interest income of the ith DMU, respectively. Conceptually, the efficiency of Bank r, $\widehat{E}_r$, is calculated as

$$\begin{aligned} \widehat{E}_r = \max \quad & \sum_{k=1}^{3} u_k \widehat{Y}_{rk} \\ \text{s.t.} \quad & \sum_{j=1}^{3} v_j \widehat{X}_{rj} = 1, \\ & \sum_{k=1}^{3} u_k \widehat{Y}_{ik} - \sum_{j=1}^{3} v_j \widehat{X}_{ij} \leqslant 0, \quad i = 1, \ldots 24, \\ & u_k, v_j \geqslant \varepsilon > 0, \quad k = 1, 2, 3, \ j = 1, 2, 3. \end{aligned} \tag{2}$$

If the observations are imprecise, then the efficiency measures will be imprecise as well. That is, the efficiency score $\widehat{E}_r$ should also appear in range. Cooper et al. (1999, 2001) propose a method that permits the mixtures of bounded data and exactly known data in a DEA model. However, their method provides only the upper bound of the efficiency scores. Kao and Liu (2000a,b) adopt the concept of membership function used in fuzzy set theory for representing imprecise data. A fuzzy

DEA model is developed to measure the fuzzy efficiencies. Recently, Despotis and Smirlis (2002) developed an approach for dealing with imprecise data in DEA. Their method is similar to that of Kao and Liu (2000a,b). In this study, we modify the method of Kao and Liu to calculate the efficiency intervals.

According to the Banking Law of the Republic of China, the total loans $\widehat{Y}_{i1}$ should not exceed the total deposits $\widehat{X}_{i1}$. All the banks have to obey this legal requirement. However, by applying the method of Kao and Liu (2000a) to calculate the minimum and maximum efficiencies, all input and output values in their corresponding ranges are considered. This total flexibility could violate the above-mentioned legal requirement. Hence, unlike previous studies, here we additionally require $\widehat{Y}_{i1} \leqslant \widehat{X}_{i1}$. This constraint has nothing to do with the decision variables u_k and v_j, which also makes the existing methods inapplicable. Therefore, we shall develop a new method to calculate the efficiency scores of the commercial banks with interval data.

Let E_r^{L} and E_r^{U} denote, respectively, the lower and upper bounds of the efficiency score $\widehat{E}_r$ of Bank r. Based on the concept of Pareto optimality, the minimal projected future efficiency E_r^{L} is calculated under the worst-case scenario for Bank r. Specifically, the output levels are set at the low estimates and the input levels are set at the high estimates for Bank r. At the same time, for the other banks, the output levels are set at the high estimates and input levels are set at the low estimates. Conversely, to calculate the maximal future efficiency E_r^{U}, the most favorable scenario for Bank r is adopted, where the outputs are at the high and the inputs are at the low estimates for Bank r, while for the other banks the outputs are at the low and inputs are at the high estimates. Note that this concept does not apply to $\widehat{X}_{i1}$ and $\widehat{Y}_{i1}$ because we need $\widehat{Y}_{i1}$ to be smaller than $\widehat{X}_{i1}$.

In mathematical forms, we require $X_{i1}^{\mathrm{L}} \leqslant x_{i1} \leqslant X_{i1}^{\mathrm{U}}$, $Y_{i1}^{\mathrm{L}} \leqslant y_{i1} \leqslant Y_{i1}^{\mathrm{U}}$, and $y_{i1} \leqslant x_{i1}$, where x_{i1} and y_{i1} are the specific values for $\widehat{X}_{i1}$ and $\widehat{Y}_{i1}$, respectively, to calculate the efficiency score. The whole idea can be formulated by the following pair of two-level mathematical programs:

$$E_r^{\mathrm{L}} = \min_{\substack{X_{i1}^{\mathrm{L}} \leqslant x_{i1} \leqslant X_{i1}^{\mathrm{U}} \\ Y_{i1}^{\mathrm{L}} \leqslant y_{i1} \leqslant Y_{i1}^{\mathrm{U}} \\ y_{i1} \leqslant x_{i1}, \forall i, i \neq r.}} \left\{ \begin{aligned} E_r = \max \quad & \sum_{k=1}^{3} u_k Y_{rk}^{\mathrm{L}} \\ \text{s.t.} \quad & \sum_{j=1}^{3} v_j X_{rj}^{\mathrm{U}} = 1, \\ & \sum_{k=1}^{3} u_k Y_{rk}^{\mathrm{L}} - \sum_{j=1}^{3} v_j X_{rj}^{\mathrm{U}} \leqslant 0, \\ & \left(u_1 y_{i1} + \sum_{k=2}^{3} u_k Y_{ik}^{\mathrm{U}} \right) - \left(v_1 x_{i1} + \sum_{j=2}^{3} v_j X_{ij}^{\mathrm{L}} \right) \leqslant 0, \\ & \quad i = 1, \ldots, 24, \ \ i \neq r, \\ & u_k, v_j \geqslant \varepsilon > 0, \quad k = 1,2,3, \ \ j = 1,2,3. \end{aligned} \right. \tag{3a}$$

$$E_r^{\mathrm{U}} = \max_{\substack{X_{r1}^{\mathrm{L}} \leqslant x_{r1} \leqslant X_{r1}^{\mathrm{U}} \\ Y_{r1}^{\mathrm{L}} \leqslant y_{r1} \leqslant Y_{r1}^{\mathrm{U}} \\ y_{r1} \leqslant x_{r1}}} \left\{ \begin{array}{ll} E_r = \max & u_1 y_{r1} + \sum_{k=2}^{3} u_k Y_{rk}^{\mathrm{U}} \\ \text{s.t.} & v_1 x_{r1} + \sum_{j=2}^{3} v_j X_{rj}^{\mathrm{L}} = 1, \\ & \left(u_1 y_{r1} + \sum_{k=2}^{3} u_k Y_{rk}^{\mathrm{U}} \right) - \left(v_1 x_{r1} + \sum_{j=2}^{3} v_j X_{rj}^{\mathrm{L}} \right) \leqslant 0, \\ & \sum_{k=1}^{3} u_k Y_{ik}^{\mathrm{L}} - \sum_{j=1}^{3} v_j X_{ij}^{\mathrm{U}} \leqslant 0, \quad i = 1, \ldots, 24, \ i \neq r, \\ & u_k, v_j \geqslant \varepsilon > 0, \quad k = 1,2,3, \ j = 1,2,3. \end{array} \right. \tag{3b}$$

To solve Model (3a), the dual of the level two program, i.e., the inner program, is formulated to become a minimization problem to be consistent with the minimization problem of level one, or outer program. The dual formulation is essentially the same as that of Model (1) which can be used to calculate the efficiency score. To derive E_r^{L}, it suffices to solve the following program:

$$E_r^{\mathrm{L}} = \min_{\substack{X_{i1}^{\mathrm{L}} \leqslant x_{i1} \leqslant X_{i1}^{\mathrm{U}} \\ Y_{i1}^{\mathrm{L}} \leqslant y_{i1} \leqslant Y_{i1}^{\mathrm{U}} \\ y_{i1} \leqslant x_{i1}, \forall i, i \neq r.}} \left\{ \begin{array}{ll} E_r = \min & \theta_r - \varepsilon \left[\sum_{j=1}^{3} s_j^+ + \sum_{k=1}^{3} s_k^- \right] \\ \text{s.t.} & \sum_{\substack{i=1 \\ i \neq r}}^{24} \lambda_i x_{i1} + \lambda_r X_{r1}^{\mathrm{U}} + s_1^+ = \theta_r X_{r1}^{\mathrm{U}}, \\ & \sum_{\substack{i=1 \\ i \neq r}}^{24} \lambda_i X_{ij}^{\mathrm{L}} + \lambda_r X_{r1}^{\mathrm{U}} + s_j^+ = \theta_r X_{rj}^{\mathrm{U}}, \quad j = 2, 3, \\ & \sum_{\substack{i=1 \\ i \neq r}}^{24} \lambda_i y_{i1} + \lambda_r Y_{r1}^{\mathrm{L}} - s_1^- = Y_{r1}^{\mathrm{L}}, \\ & \sum_{\substack{i=1 \\ i \neq r}}^{24} \lambda_i Y_{ik}^{\mathrm{U}} + \lambda_r Y_{rk}^{\mathrm{L}} - s_k^- = Y_{rk}^{\mathrm{L}}, \quad k = 2, 3, \\ & \lambda_i, s_j^+, s_k^- \geqslant 0, \quad \forall i, j, k, \end{array} \right. \tag{4}$$

where s_j^+ and s_k^- are slack and surplus variables, respectively. Now, since both level one and level two perform the same minimization operation, their constraints can be combined to form the following conventional one-level mathematical program:

$$E_r^{\mathrm{L}} = \min \quad \theta_r - \varepsilon \left[\sum_{j=1}^{3} s_j^+ + \sum_{k=1}^{3} s_k^- \right] \tag{5}$$

$$\text{s.t.} \quad \sum_{\substack{i=1 \\ i \neq r}}^{24} \lambda_i x_{i1} + \lambda_r X_{r1}^{\mathrm{U}} + s_1^+ = \theta_r X_{r1}^{\mathrm{U}}, \tag{5.1}$$

$$\sum_{\substack{i=1\\i\neq r}}^{24}\lambda_i X_{ij}^{\mathrm{L}}+\lambda_r X_{r1}^{\mathrm{U}}+s_j^+=\theta_r X_{rj}^{\mathrm{U}},\quad j=2,3, \tag{5.2}$$

$$\sum_{\substack{i=1\\i\neq r}}^{24}\lambda_i y_{i1}+\lambda_r Y_{r1}^{\mathrm{L}}-s_1^-=Y_{r1}^{\mathrm{L}}, \tag{5.3}$$

$$\sum_{\substack{i=1\\i\neq r}}^{24}\lambda_i Y_{ik}^{\mathrm{U}}+\lambda_r Y_{rk}^{\mathrm{L}}-s_k^-=Y_{rk}^{\mathrm{L}},\quad k=2,3, \tag{5.4}$$

$$X_{i1}^{\mathrm{L}}\leqslant x_{i1}\leqslant X_{i1}^{\mathrm{U}},\quad i=1,\ldots,24, \tag{5.5}$$

$$Y_{i1}^{\mathrm{L}}\leqslant y_{i1}\leqslant Y_{i1}^{\mathrm{U}},\quad i=1,\ldots,24, \tag{5.6}$$

$$y_{i1}\leqslant x_{i1},\quad i=1,\ldots,24, \tag{5.7}$$

$$\lambda_i, s_j^+, s_k^-\geqslant 0,\quad \forall i,j,k.$$

Model (5) is a non-linear program with non-linear terms $\lambda_i x_{i1}$ in (5.1) and $\lambda_i y_{i1}$ in (5.3). This non-linear program can be linearized by multiplying Constraints (5.5), (5.6), and (5.7) by λ_i and substituting $\lambda_i x_{i1}$ and $\lambda_i y_{i1}$ by p_i and q_i , respectively, to obtain the following linear program:

$$E_r^{\mathrm{L}}=\min\quad \theta_r-\varepsilon\left[\sum_{j=1}^{3}s_j^+ +\sum_{k=1}^{3}s_k^-\right] \tag{6}$$

$$\begin{aligned}
\text{s.t.}\quad & \sum_{\substack{i=1\\i\neq r}}^{24}p_i+\lambda_r X_{r1}^{\mathrm{U}}+s_1^+=\theta_r X_{r1}^{\mathrm{U}},\\
& \sum_{\substack{i=1\\i\neq r}}^{24}\lambda_i X_{ij}^{\mathrm{L}}+\lambda_r X_{r1}^{\mathrm{U}}+s_j^+=\theta_r X_{rj}^{\mathrm{U}},\quad j=2,3,\\
& \sum_{\substack{i=1\\i\neq r}}^{24}q_i+\lambda_r Y_{r1}^{\mathrm{L}}-s_1^-=Y_{r1}^{\mathrm{L}},\\
& \sum_{\substack{i=1\\i\neq r}}^{24}\lambda_i Y_{ik}^{\mathrm{U}}+\lambda_r Y_{rk}^{\mathrm{L}}-s_k^-=Y_{rk}^{\mathrm{L}},\quad k=2,3,\\
& \lambda_i X_{i1}^{\mathrm{L}}\leqslant p_i\leqslant \lambda_i X_{i1}^{\mathrm{U}},\quad i=1,\ldots,24,\\
& \lambda_i Y_{i1}^{\mathrm{L}}\leqslant q_i\leqslant \lambda_i Y_{i1}^{\mathrm{U}},\quad i=1,\ldots,24,\\
& q_i\leqslant p_i,\quad i=1,\ldots,24,\\
& \lambda_i, s_j^+, s_k^-\geqslant 0,\quad \forall i,j,k.
\end{aligned}$$

The lower bound of the efficiency score E_r^{L} can then be solved without difficulty.

In Model (3b), the outer program is to maximize the inner program under some bound constraints. Since the inner program also has an objective function of maximization, we can combine the constraints of level one and level two to form the conventional one-level program as follows:

$$
\begin{aligned}
E_r^{\mathrm{U}} = \max \quad & u_1 y_{r1} + \sum_{k=2}^{3} u_k Y_{rk}^{\mathrm{U}} && (7)\\
\text{s.t.} \quad & v_1 x_{r1} + \sum_{j=2}^{3} v_j X_{rj}^{\mathrm{L}} = 1, && (7.1)\\
& \left(u_1 y_{r1} + \sum_{k=2}^{3} u_k Y_{rk}^{\mathrm{U}}\right) - \left(v_1 x_{r1} + \sum_{j=2}^{3} v_j X_{rj}^{\mathrm{L}}\right) \leqslant 0, && (7.2)\\
& \sum_{k=1}^{3} u_k Y_{ik}^{\mathrm{L}} - \sum_{j=1}^{3} v_j X_{ij}^{\mathrm{U}} \leqslant 0, \quad i = 1, \ldots, 24, \; i \neq r, && (7.3)\\
& X_{r1}^{\mathrm{L}} \leqslant x_{r1} \leqslant X_{r1}^{\mathrm{U}}, && (7.4)\\
& Y_{r1}^{\mathrm{L}} \leqslant y_{r1} \leqslant Y_{r1}^{\mathrm{U}}, && (7.5)\\
& y_{r1} \leqslant x_{r1}, && (7.6)\\
& u_k, v_j \geqslant \varepsilon > 0.
\end{aligned}
$$

Similar to Model (5), the non-linear terms $v_1 x_{r1}$ and $u_1 y_{r1}$ in Model (7) can be linearized by substituting variables p_r and q_r, respectively, and replacing Constraints (7.4) and (7.5) with $v_1 X_{r1}^{\mathrm{L}} \leqslant p_r \leqslant v_1 X_{r1}^{\mathrm{U}}$ and $u_1 Y_{r1}^{\mathrm{L}} \leqslant q_r \leqslant u_1 Y_{r1}^{\mathrm{U}}$ accordingly. Regarding Constraint (7.6) $y_{i1} \leqslant x_{i1}$, we multiply this constraint by u_1 to become $u_1 y_{r1} \leqslant u_1 x_{r1}$ and substitute $u_1 x_{r1}$ with h_r. This constraint is then transformed to $q_r \leqslant h_r$. The resulting formulation becomes a linear program:

$$
\begin{aligned}
E_r^{\mathrm{U}} = \max \quad & q_r + \sum_{k=2}^{3} u_k Y_{rk}^{\mathrm{U}} && (8)\\
\text{s.t.} \quad & p_r + \sum_{j=2}^{3} v_j X_{rj}^{\mathrm{L}} = 1,\\
& \left(q_r + \sum_{k=2}^{3} u_k Y_{rk}^{\mathrm{U}}\right) - \left(p_r + \sum_{j=2}^{3} v_j X_{rj}^{\mathrm{L}}\right) \leqslant 0,\\
& \sum_{k=1}^{3} u_k Y_{ik}^{\mathrm{L}} - \sum_{j=1}^{3} v_j X_{ij}^{\mathrm{U}} \leqslant 0, \quad i = 1, \ldots, 24, \; i \neq r,\\
& v_1 X_{r1}^{\mathrm{L}} \leqslant p_r \leqslant v_1 X_{r1}^{\mathrm{U}},\\
& u_1 Y_{r1}^{\mathrm{L}} \leqslant q_r \leqslant u_1 Y_{r1}^{\mathrm{U}},\\
& q_r \leqslant h_r,\\
& u_k, v_j \geqslant \varepsilon > 0.
\end{aligned}
$$

The lower bound E_r^{L} and upper bound E_r^{U} of the efficiency score $\widehat{E}_r$ are solved from Models (6) and (8), respectively.

4. The result

With the input–output data of Table 1, we apply Models (6) and (8) to calculate the lower and upper bounds of the efficiency scores of the commercial banks in Taiwan. The results are shown in the last column of Table 1. Consider Bank 1. The range of efficiency score is [0.8630, 1.0], indicating that the efficiency score will never fall below 0.8630 and the best efficiency score possible is 1.0. All commercial banks except Banks 8 and 23 have an upper value of 1.0. Interestingly, Banks 6, 19, and 20 have a precise efficiency score of 1.0, although the input–output data of all banks are imprecise. This is a phenomenon of Pareto optimality. When the production frontier shifts due to variations in the input and output data, a DMU is always efficient as long as it lies on the production frontier. Most banks (19 out of 24) have a lower-bound efficiency score greater than 0.8 and three banks have a lower bound falling between 0.7 and 0.8. Only Banks 8 and 23 have a lower bound smaller than 0.6. They are far below the average of 0.8295. This is a warning to the management concerning the operations of these two banks.

To investigate how precise our predictions are, the real data of the 24 banks for Year 2000 were acquired from their financial statements published in Year 2001 as shown in Table 2. Most of the input–output data fall within the corresponding intervals shown in Table 1. There are only two input and one output values which fall outside of the forecasted ranges of Table 1. The true values of the non-interest expenses of Banks 1 and 18 are slightly higher than the upper forecasted bounds. This is because deregulation of the banking industry in 1990 has given banks in Taiwan much more operating flexibility, and many new banks were established at that time. These two banks planned to open up several new branches to increase market competitiveness. Additional bank staff and new buildings were required, which pushed up the operation costs. Regarding the value of the non-interest income of Bank 20, it is also higher than the upper bound of the forecasted value. The reason is that facing high pressure from free competition within the financial market and the trend toward electronic banking, the top management spent much time and budget to computerize technical operations. The improved services brought higher non-interest income in service charges on loans and transactions.

With the real financial data, the true efficiency scores of the 24 banks for Year 2000 can be calculated from Model (1), namely, the conventional DEA model, as shown in the last column of Table 2. As expected, all the true efficiency scores fall within the ranges of the predicted efficiencies shown in Table 1. Banks 8 and 23 have the smallest efficiency scores 0.7358 and 0.7584, respectively. These two banks had suffered from the Asian financial crisis and held many bad debts. It seems that the managers of Banks 8 and 23 were not cautious enough, and were unaware of the associated risks when new lending opportunities opened up following financial liberalization. With rapid growth in lending, those two banks could not increase the

Table 2
Real data, in million Taiwan dollars, from the financial statements and the efficiency scores of the 24 commercial banks in Taiwan

Bank	Total deposits	Interest expenses	Non-interest expenses	Total loans	Interest income	Non-interest income	Efficiency score
1	824107.208	42494.128	12473.007	741433.098	62898.027	7239.506	0.9984
2	980038.014	46845.139	16936.479	806428.970	68819.936	13291.902	0.9501
3	938204.610	42376.809	13645.024	823782.076	61385.655	12504.515	1.0
4	480609.201	31276.893	6563.065	447143.841	47438.004	6057.015	1.0
5	246440.892	8252.742	2953.079	181108.056	12221.894	1730.635	0.9913
6	268353.445	8899.696	1218.105	214366.484	12015.108	3043.514	1.0
7	113919.124	5677.476	1471.736	85624.323	8394.519	323.151	0.8959
8	80816.209	4199.700	2578.262	51235.283	5320.945	266.774	0.7358
9	401634.366	28829.179	5604.711	337615.866	36626.140	5647.270	1.0
10	531555.261	23778.723	3903.575	426360.240	40224.219	3453.882	1.0
11	177808.563	8827.725	3791.665	151727.404	12109.135	1787.591	0.9379
12	191037.580	8717.023	1628.212	163439.178	12396.810	759.830	0.9910
13	452866.887	21991.814	2820.773	373837.042	31029.289	5133.134	1.0
14	751437.532	33965.373	5286.538	633020.801	48663.376	3227.755	1.0
15	106053.669	5749.836	5159.511	82183.155	7937.822	618.807	0.8680
16	132952.168	7354.116	3207.729	130663.308	9783.182	1816.343	1.0
17	159399.890	8307.174	6263.270	131732.765	12846.278	809.854	0.9346
18	156492.640	8482.992	2931.299	135487.618	12650.628	2531.048	1.0
19	199134.585	9746.008	693.170	155294.627	14017.185	2168.116	1.0
20	227120.157	9962.417	2000.913	159534.846	13265.725	5091.513	1.0
21	137385.786	6802.984	4034.292	103615.346	9220.254	1642.579	0.8548
22	224619.732	11169.600	4871.093	185694.494	20968.487	3267.933	1.0
23	159179.571	9479.265	14765.248	100249.397	11698.965	1137.971	0.7584
24	164145.941	8184.584	1696.105	146801.986	11778.402	927.318	1.0

necessary capital fast enough to enable themselves to screen and monitor these new loans appropriately. The results were huge losses and deterioration of their balance. Moreover, the financial reports for fiscal year 2000 showed the net worth of these two banks to be less than one-half of their paid-in capital. Under Taiwan's Securities and Exchange Laws, TSEC had to terminate their stock trading on the market. To preserve financial stability, depositor interests, and social order, Banks 8 and 23 were taken over by the Financial Restructuring Fund, which is governed by the Executive Yuan of the Republic of China. The predicted efficiency scores calculated by the method proposed in this paper would have been able to provide warning of the abnormal operations of Banks 8 and 23.

In Taiwan the banking industry is very competitive. The general managers must foresee the weaknesses of their banks as compared with others and make appropriate adjustments before it is too late. For banks with a low predicted efficiency score, their inputs should be decreased and outputs be increased to have better performance. Table 1 shows that all banks except Banks 8 and 23 have a perfect upper-bound efficiency score. Therefore, we need to concentrate only on the lower-bound efficiency score to find the target inputs and outputs for each bank to raise efficiency. As revealed from Model (6), if X_{rj}^{U} is reduced to $(\theta X_{rj}^{\mathrm{U}} - s_j^{+*})$ and Y_{rk}^{L} increased to

Table 3
Target values for the 21 banks to attain perfect efficiency

Bank	Total deposits	Interest expenses	Non-interest expenses	Total loans	Interest income	Non-interest income
1	725807.485	37718.950	10985.223	724380.137	60822.392	8792.667
2	814930.775	39705.845	13661.175	786268.246	66067.139	12826.685
3	823540.889	36139.926	9337.611	770236.241	57395.587	11691.722
4	459505.178	29347.150	6158.133	418079.491	44354.534	6331.953
5	192227.702	6997.840	1517.306	169336.032	11427.471	2519.972
7	87486.467	4215.482	1162.389	80058.742	7848.875	896.658
8	50783.892	2639.039	1515.742	47904.990	4975.084	586.368
9	347918.156	21506.120	4855.114	339893.623	35344.225	5393.143
10	464263.400	22272.508	3656.311	402910.427	37609.645	5994.767
11	148505.301	7300.965	2144.019	147175.582	11443.133	1671.398
12	165173.528	7462.959	1393.971	158536.003	11618.825	1339.019
13	389430.303	18367.311	2425.645	349537.634	29012.385	4799.480
14	625967.017	28570.079	4532.716	591874.449	45500.257	4306.516
15	80001.929	4337.407	3072.658	78813.646	7421.864	578.585
16	122170.193	6694.269	2184.845	122170.193	10873.149	2000.649
17	131600.397	6871.712	2419.029	127122.118	12139.733	1984.710
18	136710.780	7410.677	2312.265	126680.923	11828.337	2366.530
21	105413.277	5245.128	1814.061	101543.039	8989.748	1593.302
22	226599.307	11268.038	3229.737	211239.275	19395.850	3022.838
23	100546.445	5987.618	1663.729	97124.855	10657.757	1465.067
24	145101.133	7234.979	1499.317	144453.154	11601.726	977.706

$Y^{\mathrm{L}}_{rk} + s_k^{-*}$, then Bank r will be efficient. Banks 6, 19, and 20 have a perfect lower-bound efficiency score; thus, no improvement is needed. For other banks, their target inputs and outputs are calculated and shown in Table 3. Consider Bank 1 again. Its lower-bound efficiency score is 0.8630. To become efficient, the total deposits, interest expenses, and non-interest expenses should be controlled at the target values of 725807.485, 37718.950, and 10985.223 million Taiwan dollars, respectively. Regarding the output, the total loans, interest income, and non-interest income should be increased to the target values of 724380.137, 60822.392, and 8792.667 million Taiwan dollars, respectively. If some target values are too difficult for a bank to achieve, then other target values that are feasible to this bank can be generated by applying the model of Kao (1994).

5. Conclusion

Rapid changes in the economic environment has raised the need to evaluate the risks and returns involved in banking, especially after the financial liberalization in East Asia. DEA is able to measure the efficiency of the banking industry. However, because it is applied in an ex post facto manner, banks might not have time to react appropriately. Based on the financial forecasts of the 24 commercial banks in Taiwan, this paper predicts the efficiency scores in advance for providing look-ahead information for bank operations. Since considerable uncertainty is involved in financial forecasts, a pessimistic and an optimistic estimate are supplied to represent the financial data. A DEA model for interval data is developed to calculate the efficiency scores. The results are also in ranges. As a matter of fact, a reliable interval estimation is more informative than an unreliable point estimation of the efficiency score for cases of imprecise data. Notably, even though all banks have imprecise observations, it is possible that some banks have precise efficiency scores. This happens when the whole ranges of the input–output data of a DMU lie on the production frontier.

There exist some differences in the input–output data between the financial forecasts and the real data shown in the financial statements published afterwards. However, the impact on efficiency measurement is not great. The true efficiency scores calculated from the real data all fall within the ranges of the predicted efficiency scores calculated from the financial forecasts. The predicted efficiency scores are able to disclose some operating problems for the banks in advance. These results show that the solution method proposed in this paper is able to predict the bank performance based on their financial forecasts. They also confirm that this study has selected proper input and output factors to measure the efficiencies of the banks.

Several financial ratios have been used to detect a possible financial crisis in a company. The popular ratios include (net worth)/(total assets), (total operating income)/ (total assets), (net income)/(total assets), and (current assets)/(current liabilities). A problem with these ratios is that a company may perform differently in different ratios. In this study, we have calculated these four ratios for 24 banks based on their financial statements. As expected, every bank performs differently in each ratio. The ratio of (net worth)/(total assets) indicates that Banks 8 and 23 have the worst performance as concluded in the current study. However, for the other ratios the conclusions are different. It is difficult to derive a general consensus conclusion from these ratios.

Taiwan is gradually recovering from the Asian financial crisis and is currently performing a series of financial reforms to regulate banking operations. The evaluation of bank performance via DEA discussed in this paper might not be able to replace the on-site examination conducted by government agencies, however, it is able to provide part of the early-warning information needed in financial supervision beforehand. It is a tool worthy of consideration by bank managers and government officials for planning, operation, and control.

The proposed methodology has another application for future study. Every year, the input and output data for each bank fluctuate. Consequently, the efficiency score of each bank also fluctuates. The efficiency scores of a specific year only give a snapshot of the performance of the banks being evaluated. It will be more informative if we could have a more comprehensive picture of the performance of the banks. One possible way is to treat the banks data as imprecise, and use the smallest and largest observations for each factor for each bank as it appeared in the past as the lower and upper bound of the interval-valued data. With this interval-valued data, the model of this paper can be applied to calculate the minimum and maximum efficiency scores for each bank. The associated efficiency intervals would give a general idea of the relative performance of the banks in the past.

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