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Online banking performance evaluation using data envelopment analysis and principal component analysis

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ABSTRACT

This paper presents a hybrid approach to conducting performance measurements for Internet banking by using data envelopment analysis (DEA) and principal components analysis (PCA). For each bank, DEA is applied to compute an aggregated efficiency score based on outputs, such as web metrics and revenue; and inputs, such as equipment, operation cost and employees. The 45 combinations of DEA efficiencies of the studied banks are calculated, and used as a ranking mechanism. PCA is used to apply relative efficiencies among the banks, and to classify them into different groups in terms of operational orientations, i.e., Internet banking and cost efficiency focused orientations. Identification of operational fitness and business orientation of each firm, in this way, will yield insights into understanding the weaknesses and strengths of banks, which are considering moving into Internet banking.

1. Introduction

Since the introduction of Internet banking, and due to its growing convenience for most individuals, the Internet market has grown into a profitable competitive venue for the banking industry. Improving the efficiency of Internet banking is now considered to be important to the banking industry and this research aims to help clarify the issue by proposing a new method.

In 2000, it was reported by the Economist that online banking costs firms approximately $0.01 per transaction and accounted for only 1% of all banking transactions. This is a situation which is changing rapidly. In a report by Jupiter Research in 2004, an estimated 30 million families in the US used Internet banking. It was forecasted by Jupiter that in 2008, those numbers will reach 56 million [1]. Internet banking can reduce business operation costs and has decreased the distribution of branch locations. However, lack of research has stymied its growth.

Looking at the data already being gathered on web efficiency within the wider analysis of e-commerce is the first step in addressing this problem. Electronic commerce (EC) is the process of electronically conducting all forms of business between entities in order to achieve the organization's objectives [2]. For the dot com market, non-financial information normally takes the form of web metrics, which can be obtained from Internet traffic measurement reports, or websites such as Alexa.com. The impact of Internet firms can be assessed by examining "unique visitors" who access the websites or by the number of "page hits" [3]. Demers and Lev stated that web traffic measurements have become standard performance benchmarks that are now commonly reported in the business press [4]. They cited three dimensions of web traffic performance, "reach", "stickiness", and "customer loyalty", respectively, as performance measurements for evaluating a firms' Internet profile. "Reach" is thought to be important when the firm obtains revenues from advertising. "Stickiness" is considered relevant for dot com firms whose revenue depends on the time that the user spends in the web site; this is often an unusual way of generating income. "Customer loyalty" considers repeated sales to a particular customer.

Online performance assessment has been an emerging research area for both researchers and practitioners. While scope of the existing literature is generally thought to be financial performance, the findings of a recent study from Serrano-Cincaa et al. suggest that without the help of supporting non-financial information financial information might not always be sufficient to judge an online business [3]. It is possible for various performance evaluation models to be constructed by combining all the possible inputs and outputs that a bank might use. Traditionally used ratio analysis can provide a relatively insignificant amount of information when considering the effects of scale economies, the identification of benchmarking policies, and the estimation of overall performance measures of firms. As a result, there may be incentive to utilize more effective methods in evaluating the overall performance of banks [5].

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Studies on bank performance evaluation in literature mainly employ five different approaches, i.e., DEA (e.g., [6,7]), free disposal hull (e.g., [8]), stochastic frontier approach (e.g., [9]), also called econometric frontier approach (e.g., Berger and Humphrey [9]), thick frontier approach (e.g., [10]), and distribution free approach (e.g., [11]). These approaches primarily differ in how much restriction is imposed on the specification of the best practice frontier and the assumption of random errors and inefficiency [12]. Compared to other approaches, DEA is considered a better way to organize and analyze data since it allows efficiency to change over time and requires no prior assumption on the specification of the best practice frontier. Thus, DEA has become a leading approach for performance analysis in banking industry, in literature. DEA provides each bank with an efficiency score while hardly generating insights regarding why and how banks achieve a certain level of efficiency. Multivariate statistical techniques such as principal component analysis (PCA) have been proposed to select appropriate DEA models from a set of models combining all the possible inputs and outputs that an organization might use [13].

This study uses both data envelopment analysis (DEA) and the statistical approach of PCA to gauge online banking performance and find the operational orientation (in relation to Internet banking) for Taiwan banks. Both financial and non-financial variables are employed under the DEA framework to measure the online banking performance. PCA is applied to the bank efficiency values to identify different company strategic groups [13]. This allows decision makers to understand different business operations and orientations among various banks. Our study indicates the existence of two obvious business strategies in the Taiwan banking sector, i.e., “Cost Oriented” and “Internet oriented” strategies. Identification of operational fitness and business orientation of each firm, in this way, should yield insights into understanding weaknesses and strengths of a bank of moving into Internet banking.

The rest of the paper is structured as follows: the second section reviews prior research related to e-commerce and Internet banking; the third section describes the DEA methodology used, and introduces the 45 combinations of DEA models in the analysis; the fourth section shows PCA programming analysis and gives the results and final findings. The last section draws conclusions and suggests directions for future research.

2. Literature review

This section investigates literature in both EC and Internet banking respectively.

2.1. Electronic commerce

Electronic commerce (e-commerce) is no longer considered a new phenomenon. Many studies have been conducted in the last decade on e-commerce and related activities. The most common belief about e-commerce is that it is still difficult to gain customers online, whereas it is very easy to lose them. Hence, e-companies are generally under intense pressure to provide better value than their online and physical competitors. Therefore, an emerging question is how to assess overall performance of e-companies in the electronic age. Liang et al. investigated how firms' e-commerce performance [14] was affected by characteristics unique to their respective industries. The research found that increased net access has encouraged firms to use web based e-commerce to expand their markets, and that e-commerce most benefits industries with high information intensity products. In Liang et al.'s work, industrial characteristics can affect e-commerce performance significantly and the results show that its impact on the banking industry is higher than in software, advertising, and others. Wen et al. use DEA to evaluate the relative efficiency of e-commerce firms in 2003 and use a model to help management identify inefficient operations [15]. Wen et al. combine financial variables, operational variables, and e-commerce specific variables as the input and output variables for the DEA model to measure e-commerce efficiency [15]. The results show that e-commerce efficiency cannot be determined only by annual sales or any single input or output measure. All key variables from financial, operational, and e-commercial specific measurement need to be measured and analyzed as they relate to each other. Other tools, to conduct an online performance assessment, include analytic hierarchy process [16], and content analysis [17].

2.2. Internet banking

Internet banking systems provide easy access to banking services. It is accepted that the interaction between user and bank has been substantially improved by ATMs, telephone banking, Internet banking, and more recently, mobile banking [18]. The definitions are followed below in the research: Furst et al. state that Internet banking refers to the use of the Internet as a remote delivery channel for banking services, such as opening a deposit account, transferring funds among different accounts, and electronic bill presentment and payment [19]. Stefan defined it as using the Internet, or a direct connection through a modem; people can access their banks and conduct transactions 24 h a day, with reduced costs and increased convenience [20]. Nowadays, to address the security issue, most Taiwan banks issue silicon-chip ATM cards, and provide Internet ATM/web-ATM services online. Internet ATM relies on a small desktop device into which users can insert their normal silicon-chip ATM cards, just as they would with traditional ATMs [21]. Our research looked into the Internet banking channel, and therefore, its research objectives include Internet banking and Web ATM banking, as these two channels induce customers to use the banks' web services.

Most banks that operate over the Internet use a “click and mortar” business strategy, maintaining traditional networks of brick and mortar branches as well as transactional websites. Only a small number of banks in US have completely abandoned physical branches in favor of a pure Internet business strategy, relying exclusively on transactional websites to deliver banking services [22]. Using the definition and model of e-commerce adopted by Liang et al. in 2004: Internet bank strategy in Taiwan belongs to the Hybrid Model (click-and-mortar companies also offer virtual services with online order processing and customer services functions). It is generally thought that the multichannel strategy has become the most popular business model for banks [23], while client structure has become diversified, in which 65% of clientele will use a multichannel banking procedure that includes branches, Internet, and telephone. Given this multichannel strategy, banks need to be sure that all clients can be switched from being branch users to Internet users or to use combined channels [23].

In Taiwan 40% of all Internet users had used Internet banking websites in 2003, and in 2005 there were 4.6 million e-accounts in Taiwan, for an impressive penetration rate of 57.5% [14]. Two important factors are said to contribute to this rapid market spread over the last few years: first, Internet ATM has bolstered the online banking market in Taiwan, and second, the growth of the Internet auction market. MIC Taiwan (Market Intelligence Center) reported that Taiwan's auction market reached a scale of NT$ 31.7 billion in 2005 and grew 65% from the year before. This is why most banks have poured capital into Internet banking channels and are providing value in this market.

3. Efficiency in Internet firms

During the last decade, efficiency measurement approaches have evolved very quickly. Among these, the advantage of non-parametric techniques has been widely recognized [24,25]. We employ in this section a leading non-parametric efficiency measurement technique to evaluate online banking companies.

3.1. DEA model specification

DEA is commonly used in literature to assess the relative financial efficiencies of Internet companies. Because a variety of factors often affect financial performance of an online company, DEA has received emerging attention in literature [26]. In the literature, researchers tend to narrowly focus on the financial performance of Internet companies. However, financial information may not always explain the reasons for failures or success in an e-business environment. Therefore, motivation is taken into account regarding non-financial performance measures. This study combines financial and non-financial variables as the input and output variables for DEA. This method combined four input variables and two output variables (raw data were shown in Appendix A); therefore, there are 45 combinations and efficiency scores for 32 banks in Taiwan by using different combinations of input and output variables based on 2005 data. Input and output data of these companies are obtained from of each bank's annual report from 2005 and the web metric numbers (daily reach) are collected from Alexa.com.

The DEA method was invented by Charnes et al. [27]. They conducted a mathematical programming model to measure the efficiency frontier by Pareto optimality. This approach was created to determine the organization relative efficiency using multiple measures of input and output [28]. This technique also allows an analysis of return to scale for economic units of interests [28]. DEA has a rich literature base of over 3000 papers and several books [26] and has become a new popular approach in operational research for measuring banking efficiency.

A standard procedure is to estimate a mode that includes all four inputs and both output variables. Since the model contains four inputs A, B, C, and D, and two outputs, 1 and 2, it will be described as model ABCD12, and has 45 combinations or model probabilities, and therefore creates 45 DEA results. Serrano-Cinca et al. stated two reasons to run different combinations for different variables [3]: first, all combinations of inputs and outputs are equivalently assessed. Second, since efficiency results depend on the choice of inputs and outputs, the efficiency score of each sampling bank had to be found. After testing the 45 combinations, the weaknesses and the strengths of each firm can be understood. The definitions and all four inputs, two output variables codes are listed as follows:

Financial—Input variables:
A: Deposit ($000): Deposit and remittance released.
B: Operation cost ($000): Operation cost includes operation expense and excludes non-operation income, expenses, interest, and loss.
C: Employees (people): Total employees in 2005.

EC—Input variables:
D: Equipment ($000): PC equipment and investment, IT expenses, software expenses, and hardware expenses released from the bank's balance sheet.

Financial—Output variables:
1: Revenue ($000): Revenue from operation by this firm's income statement.

EC—Output variables:
2: Daily Reach rate (million/day): This number is collected from Alexa.com.

"Reach" is a measurement of the number of users per million. It is expressed as the percentage of all Internet users who visit a given site.

3.2. DEA results

The DEA computation is implemented using 45 combinations of variables. In Table 1, the computed efficiencies and their four statistic values are presented: minimum, maximum, mean, and standard deviation.

In the 45 DEA combinations in Table 1, the efficiency score achieved is in percentage values from 0 to 100; the results show some interesting features. Seven banks including Chinatrust, Cathay United, Taishin Bank, E. Sun Bank, Far Eastern International Bank, Cosmos Bank, and Chinese Bank are 100% efficient under the complete model (ABCD12), as representing overall efficient companies, if all the six variables are used. That said, this level of discrimination is insufficient—some specific features are not revealed by the full model. From the 45 combinations, some firms have achieved lower scores under certain models; there are distinguishing features among them, since these seven achieve varied efficiency scores under different models. Therefore, from the combinations, relative weaknesses and strengths can be assessed. Chinatrust was chosen as an example to pinpoint the details. Table 1 shows that Chinatrust is 100% efficient under ABCD12, and another 29 models, but only 39% efficient under models D12 and D2, and only 21% efficient under model D1. Therefore, Chinatrust is fully efficient when all its aspects are considered, and their strength is efficiently using the input A (deposit), B (operation cost), and C (employees) to offset deficiencies in D (equipment) whose utilization is relatively poor. The statistic summary indicates that some banks can be very inefficient and yield an efficiency value of no larger than 10%, when the second output variable web reach is used independently in models A2, B2, C2, D2, AB2, AC2, AD2, BC2, BD2, CD2, ABC2, ABD2, ACD2, BCD2, and ABCD2. When web reach is excluded or simultaneously employed with output variable "revenue", that much difference in different bank efficiencies cannot be diagnosed. While this interesting pattern on the non-importance of some variables cannot be simply relied on, it can be concluded that more technique is required to pinpoint various patterns under this result.

DEA testing creates the efficiency score, which can be seen as a ranking per specific model. This, in turn, can reveal features of each bank as it is tracked through the 45 combinations; the efficiency scores for sampling banks can be used to understand the weaknesses and the strengths of each firm, per factor, and among combinations of factors that are functionally highly interdependent. This is certainly promising, which is why multivariate analysis was used to unleash the full power of the DEA method, as follows.

4. Multivariate analysis of DEA efficiency scores

In order to reveal the full depth of the data, multivariate analysis was applied to analyze the efficiency values in Table 2. Differences and similarities between the 32 were revealed using PCA. PCA depends on numerical number, specifically, the DEA efficiency ratings. Unfortunately, as is well known, DEA efficiency ratings are very sensitive to actual values in the data used to calculate them, and it must be admitted that even tiny changes in the raw data will have an appreciable impact on the DEA efficiencies and, in turn, on the results of PCA analysis.

Table 1
DEA 45 combinations result and summary statistics.

	A1	B1	C1	D 1	AB1	AD1	BC1	BD1	CD1	AC1	ABC1	BCD1	ABD1	ACD1	ABCD1	B2	A2	C2	D2	AB2	AD2	AC2	BC2
Bank of Taiwan	32	44	80	21	47	38	83	70	94	80	83	94	70	94	94	23	25	67	28	31	44	67	67
Cooperative	35	68	68	16	68	40	79	73	76	68	79	79	73	76	79	12	10	20	8	12	14	20	20
Land Bank	33	67	71	22	67	39	81	86	89	71	81	91	86	89	91	14	10	24	12	14	18	24	24
First Bank	46	56	60	21	66	52	69	78	80	65	69	81	78	80	81	21	26	37	20	32	39	37	37
Chinatrust Comm	67	100	85	21	100	72	100	100	97	94	100	100	100	98	100	72	73	100	39	91	90	100	100
CHANG HWA	44	20	60	16	44	48	60	38	71	64	64	71	49	71	71	5	16	23	10	16	21	23	23
Taiwan Busi	35	35	49	18	48	41	54	57	67	52	54	67	57	67	67	12	19	28	16	23	29	28	28
Cathay United	66	47	100	19	81	70	100	69	100	100	100	100	83	100	100	5	11	17	5	12	12	17	17
Taishin Bank	100	36	65	22	100	100	68	64	85	100	100	85	100	100	100	24	100	70	38	100	100	100	70
E. SUN Bank	51	100	47	14	100	54	100	100	59	62	100	100	100	64	100	100	78	78	36	100	88	93	100
SinoPac Bank	56	48	82	20	73	62	86	70	92	84	86	92	76	92	92	11	20	32	12	24	27	32	32
Hi Bank	56	52	43	6	74	56	52	52	43	62	74	52	74	62	74	22	36	30	7	43	36	39	30
Shanghai	59	71	82	21	85	65	92	87	94	86	92	96	87	94	96	43	54	81	32	43	46	52	52
Shin Kong	57	40	37	19	69	62	43	62	56	57	69	62	73	64	73	3	6	4	3	7	7	6	4
Union Taiwan	73	33	44	17	74	74	48	53	60	73	76	60	77	74	78	26	87	56	34	92	89	87	56
Fuhwa Bank	50	42	36	16	65	54	43	58	52	54	65	58	67	57	67	18	33	26	17	39	40	35	26
TC Bank	62	46	44	21	77	68	51	71	65	65	77	71	81	71	81	17	34	26	20	40	44	36	26
Far Eastern	76	46	59	46	87	89	65	95	100	84	90	100	98	100	100	20	49	41	50	55	82	54	41
Overseas Chin	42	40	37	13	56	45	43	51	49	50	56	52	57	52	57	15	23	22	12	27	28	27	22
EnTie Bank	64	42	58	35	75	74	64	82	93	77	79	93	84	93	93	16	37	37	34	42	59	44	37
Taichung Bank	39	41	38	8	53	39	45	41	41	49	53	45	53	49	53	23	33	35	12	40	33	41	35
JihSun Bank	66	41	39	15	76	66	45	57	54	66	76	57	77	66	77	30	73	47	29	82	75	73	47
Cosmos Bank	100	44	51	18	100	100	57	64	67	100	100	68	100	100	100	13	43	24	13	46	43	43	24
Chinese Bank	80	40	39	100	85	100	45	100	100	80	85	100	100	100	100	16	48	25	100	51	100	48	25
BOWA Bank	54	33	47	18	62	59	51	55	65	63	66	65	66	68	69	5	13	12	8	15	17	15	12
Pan Hsin	44	43	30	14	59	47	43	56	45	45	59	56	61	50	61	21	32	24	18	39	40	33	26
King's Town	38	39	27	7	52	38	39	39	31	40	52	39	52	40	52	13	19	14	6	23	19	19	16
Chin Fon	77	41	61	25	83	83	66	71	86	86	89	86	89	92	93	21	60	52	33	66	75	67	52
Kaohsiung	39	50	43	10	57	41	51	50	48	52	57	51	57	52	57	21	25	30	11	31	27	32	30
Taipei Fubon	71	62	75	20	93	74	84	80	88	92	96	90	94	93	96	33	56	65	27	67	65	72	65
HUA NAN	45	53	60	16	64	49	68	66	71	64	68	72	66	71	72	18	23	33	14	28	30	33	33
Taipei	54	50	57	16	72	57	64	64	69	70	73	70	73	72	74	11	17	20	9	21	21	22	20
Min	32	20	27	6	44	38	39	38	31	40	52	39	49	40	52	3	6	4	3	7	7	6	4
Max	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Mean	57	49	55	21	72	61	64	67	71	70	77	75	77	77	81	22	37	38	22	42	46	44	37
Std	17.9	17.1	18.0	16.2	16.2	18.7	18.9	17.3	20.1	16.7	15.4	18.6	15.8	18.2	15.8	19.1	24.5	22.6	18.7	26.8	27.9	25.5	22.9

	BD2	CD2	ABC2	BCD2	ABD2	ACD2	ABCD2	A12	B12	C12	D12	AB12	AC12	AD12	BC12	BD12	CD12	ABC12	BCD12	ACD12	ABD12	ABCD12
Bank of Taiwan	61	71	67	71	61	71	71	32	44	89	28	48	89	44	89	70	96	89	96	96	70	96
Cooperative	19	20	20	20	19	20	20	35	68	70	16	68	70	40	79	73	76	79	79	76	73	79
Land Bank	27	28	24	28	27	28	28	33	67	73	22	67	73	39	81	86	89	81	91	89	86	91
First Bank	47	49	37	49	47	49	49	46	56	65	21	66	67	52	69	78	80	69	81	80	78	81
Chinatrust Comm	100	100	100	100	100	100	100	73	100	100	39	100	100	90	100	100	100	100	100	100	100	100
CHANG HWA	17	24	23	24	21	24	24	44	20	62	16	44	64	48	62	38	71	64	71	71	49	71
Taiwan Busi	34	38	28	38	34	38	38	35	35	53	18	48	53	41	54	57	67	54	67	67	57	67
Cathay United	12	17	17	17	13	17	17	67	47	100	19	81	100	70	100	69	100	100	100	100	83	100
Taishin Bank	76	90	100	90	100	100	100	100	36	75	38	100	100	100	75	76	90	100	90	100	100	100
E. SUN Bank	100	89	100	100	100	94	100	78	100	78	36	100	93	88	100	100	89	100	100	94	100	100
SinoPac Bank	27	32	32	32	29	32	32	56	48	85	20	73	85	62	86	70	92	86	92	92	76	92
Hi Bank	22	30	43	30	43	39	43	56	52	47	7	74	62	56	52	52	47	74	52	62	74	74
Shanghai	50	53	52	53	50	53	53	59	71	88	21	85	89	65	92	87	95	92	96	95	87	96
Shin Kong	7	7	7	7	8	7	8	57	40	37	19	69	57	62	43	62	56	69	62	64	73	73
Union Taiwan	71	79	92	79	92	89	92	87	33	56	34	92	87	89	56	71	79	92	79	89	92	92
Fuhwa Bank	40	39	39	40	43	42	43	50	42	40	17	65	54	54	43	58	52	65	58	57	67	67
TC Bank	43	44	40	44	47	46	47	62	46	47	21	77	65	68	51	71	65	77	71	71	81	81
Far Eastern	83	94	55	94	85	94	94	76	46	64	50	87	84	89	65	95	100	90	100	100	98	100
Overseas Chin	28	28	28	28	30	29	30	42	40	40	13	56	50	45	43	51	49	56	52	52	57	57
EnTie Bank	61	70	44	70	62	70	70	64	42	63	35	75	77	74	64	82	93	79	93	93	84	93
Taichung Bank	31	35	42	35	40	41	42	39	41	43	12	53	50	39	45	41	43	53	45	50	53	53
JihSun Bank	66	66	82	66	82	75	82	73	41	47	29	84	73	75	47	66	66	84	66	75	84	84
Cosmos Bank	30	31	46	31	46	43	46	100	44	53	18	100	100	100	57	64	67	100	68	100	100	100
Chinese Bank	100	100	51	100	100	100	100	80	40	42	100	86	80	100	45	100	100	86	100	100	100	100
BOWA Bank	16	18	15	18	18	18	18	54	33	47	18	62	63	59	51	55	65	66	65	68	66	69
Pan Hsin	42	39	39	42	44	41	44	44	43	33	18	59	45	47	43	56	45	59	56	50	61	61
King's Town	15	15	23	16	23	19	23	38	39	28	7	52	40	38	39	39	31	52	39	40	52	52
Chin Fon	66	76	67	76	77	79	79	77	41	68	33	86	86	83	68	71	87	89	87	93	90	93
Kaohsiung	28	30	33	30	31	32	33	39	50	47	11	57	53	41	51	50	48	57	51	53	57	57
Taipei Fubon	64	68	72	68	70	72	72	71	62	84	27	93	94	74	84	80	90	96	90	94	94	96
HUA NAN	33	35	33	35	33	35	35	45	53	64	16	64	66	49	68	66	71	68	72	71	66	72
Taipei	21	22	22	22	23	23	23	54	50	58	16	72	70	57	64	64	69	73	70	72	73	74
Min	7	7	7	7	8	7	8	32	20	28	7	44	40	38	39	38	31	52	39	40	49	52
Max	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Mean	45	48	46	49	50	51	52	58	49	61	25	73	73	64	65	69	74	78	76	79	77	82
Std	27.0	27.7	26.3	28.2	28.7	28.4	28.8	19.0	17.1	19.4	16.9	16.7	17.8	20.2	19.0	17.0	19.9	15.7	18.4	18.4	16.0	16.0

A: deposit; B: operation cost; C: the number of employees; D: equipment; 1: revenue; 2: web reaches.

Table 2
PCA, matrix of component loadings (models).

Model	PC1	PC2	Model	PC1	PC2	Model	PC1	PC2
A2	.744	−.563	A12	.747	−.306	A1	.673	−.234
B2	.588	−.221	B12	.481	.255	B1	.481	.256
C2	.756	−.129	C12	.652	.635	C1	.503	.780
D2	.708	−.374	D12	.689	−.254	D1	.471	−0.098
AB2	.739	−.574	BC12	.636	.638	BC1	.605	.672
BC2	.755	−.193	AD12	.840	−.262	CD1	.706	.544
AC2	.802	−.409	CD12	.843	.423	AD1	.715	−.192
AD2	.825	−.548	AB12	.853	–	BD1	.796	.257
BD2	.842	−.422	BD12	.870	.150	AC1	.801	.375
CD2	.856	−.400	AC12	.898	.291	AB1	.843	–
ABC2	.783	−.456	BCD12	.857	.411	ACD1	.792	.435
BCD2	.855	−.405	ABC12	.908	.226	ABC1	.895	.303
ABD2	.830	−.525	ACD12	.902	.335	BCD1	.801	.495
ACD2	.850	−.460	ABD12	.927	–	ABD1	.918	–
ABCD2	.839	−.487	ABCD12	.925	.269	ABCD1	.907	.339

A: deposit; B: operation cost; C: the number of employees; D: equipment; 1: revenue; 2: web reaches; –: close to 0.

4.1. PCA results

PCA can be also called the Karhunen–Loève transform (KLT), named after Kari Karhunen and Michel Loève. PCA is a standard data reduction technique which extracts data, removes redundant information, highlights hidden features, and visualizes the main relationships that exist between observations [29]. While deriving statistics, PCA is a technique for simplifying a data set, by reducing multi-dimensional data sets to lower dimensions for analysis [30]. Unlike other linear transform methods, PCA does not have a fixed set of basis vectors. Its basis vectors depend on the data set, and PCA has the additional advantage of indicating what is similar and different about the various models created. PCA also processes all combinations and DMUs in a very powerful way, identifying similarities, differences, and discordant behavior [3] among them.

Two principal components are associated with eigenvalues greater than 1 (the more components, the lower eigenvalues, but the eigenvalue needs to be higher than 1 to be a component), while the total eigenvalue is 4.691, of which the first principal component accounts for 61.02% of the total variance and second accounts for a further 15.50% of the variance. The total of these two components reaches 76.52% of the accumulated variance.

In order to interpret the revealed PCA information, the component loadings must be studied. Table 2 shows the matrix of component loadings. All models are weighted with a positive sign on the first component and other variables; thus, the first component is named "overall measure of efficiency", and is the higher weighted value in general. The highest weight is associated with ABD12 (.927), followed by the complete model, ABCD12 (.925), model ABD1 (.918), ABC12 (.908), ABCD1 (.907), and ACD12 (.902). In the first component, the model ABD12 is higher than the complete model, ABCD12; so the author can conjecture that input C, the number of employees, has less contribution to the overall measurement. However, it cannot be concluded that any model with the input C will drop the loading, because if only models with a single input, such as model A1 switching to model AC1 (or model A2 switching to model AC2 and model B1 switching to model BC1, etc.), are focused on, the loading value will increase. Therefore, it can just be concluded that if variable A (deposit), B (operation cost), D (equipment), 1 (revenue), and 2 (web reaches) were considered at same time, the input C (the number of employees) is less important.

Beyond the first, principal component, distinguishing orientation from the analysis is desired. When interpreting the second component, the sign and the variables need to be considered together. The second principal component is associated with specialization in Internet impact and the efficient use of inputting cost. In the second component (PC2), there are two parts. The first is the model with 1, web reach, and the second, without web reach. It is easy to recognize the sign of the loading value in PC2. It can be seen that models A2, B2, C2, D2, AB2, BC2, AC2, AD2, BD2, CD2, ABC2, BCD2, ABD2, ACD2, and ABCD2 are associated with negative loadings, and all of these models have output 2 (web reach) in their definition. Thus it can be said that these are "Internet oriented". As for the rest, the models with output 1, revenue, and positive weights, are associated with the input B (operation cost) or input C (the number of employees). Models B12, C12, BC12, CD12, AB12, BD12, AC12, BCD12, ABC12, ACD12, ABD12, ABCD12, B1, C1, BC1, CD1, BD1, AC1, AB1, ACD1, ABC1, BCD1, ABD1, and model ABCD1 load positively on this component. These two variables, operation cost (input B) and the number of employees (input C), belong to the cost in bank operation; this makes their privileged use "Cost Oriented". In order to interpret what PCA reveals, the component loadings must be studied further.

From the above geographical map (Fig. 1) the models may be understood better. The plots of principal component loadings are converted from the matrix of component loadings and show a set of directional vectors, interpreting them from south to north and from west to east directions. The plots of the loading are along vector IV and I in this figure. Horizontal is from west to east, representing the "overall measure of efficiency"; the more overall efficient ones will be located in the right direction. From zero to north and south, respectively, are the "Cost Oriented" and "Internet oriented" models. Therefore, the more cost-wise efficient ones will be found in the north, and the more net-wise efficient are in the south. Finally, vector I is populated with models by overall measured efficiency and cost efficiency orientation, and vector IV with overall measured efficiency and Internet orientation. These two directional vectors will help to show the key differences between banks.

4.2. Efficiency in individual dot com firms

Efficiency scores of 45 DEA combinations in Table 1 can be analyzed, and yield valuable information for different banks. Plotting helps considerably in viewing the 32 banks as a whole. Fig. 2 produces a very good representation of DEA efficiency for these 32 banks in Taiwan, since the first two principal components account for 76.5% of total variance. When PCA was performed on rankings, the results were essentially unchanged.

Firms are identified in Fig. 2 by means of their ticker. On the extreme right hand side is Chinatrust Bank (CHINATRU), a firm that is 100% efficient under 30 out of the 45 models. On the extreme left hand side is the King's Town Bank (KINGSTON), a firm that achieves very low efficiency scores under all models. Efficiency clearly

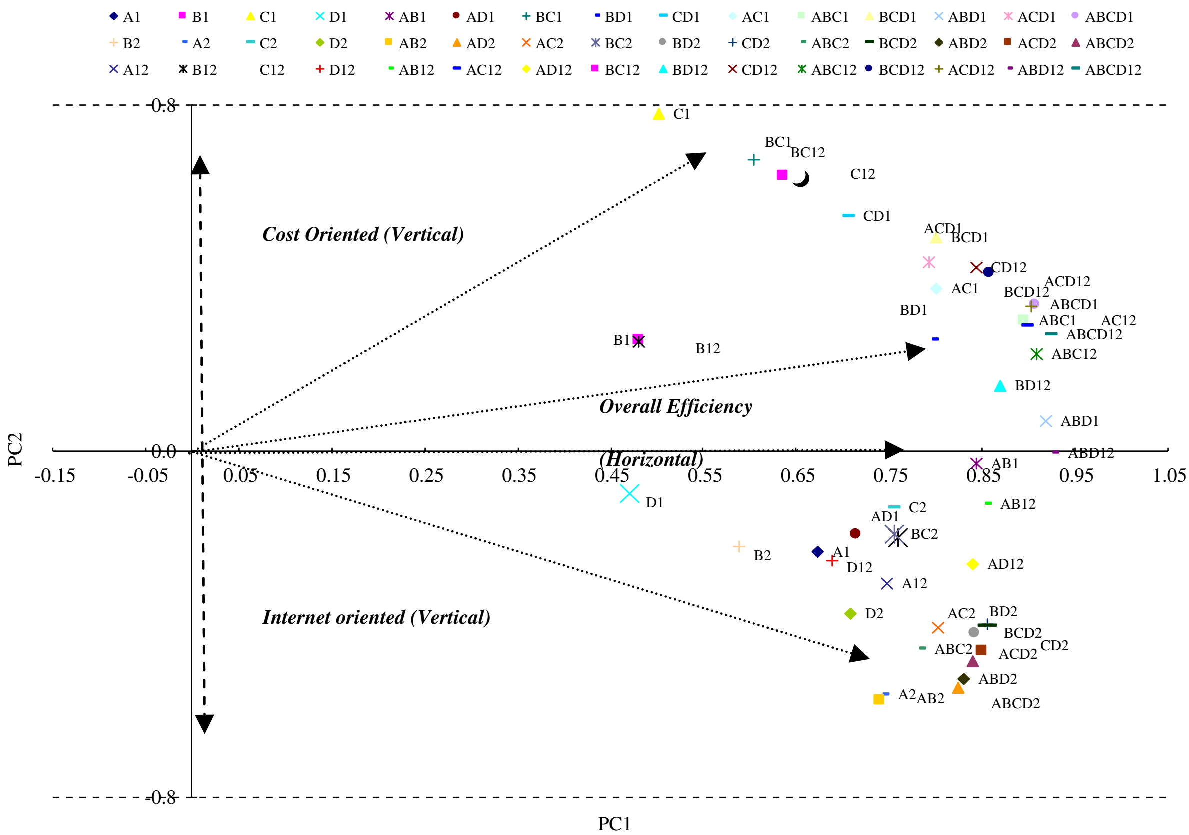

Fig. 1. Plots of principal component loadings (models).

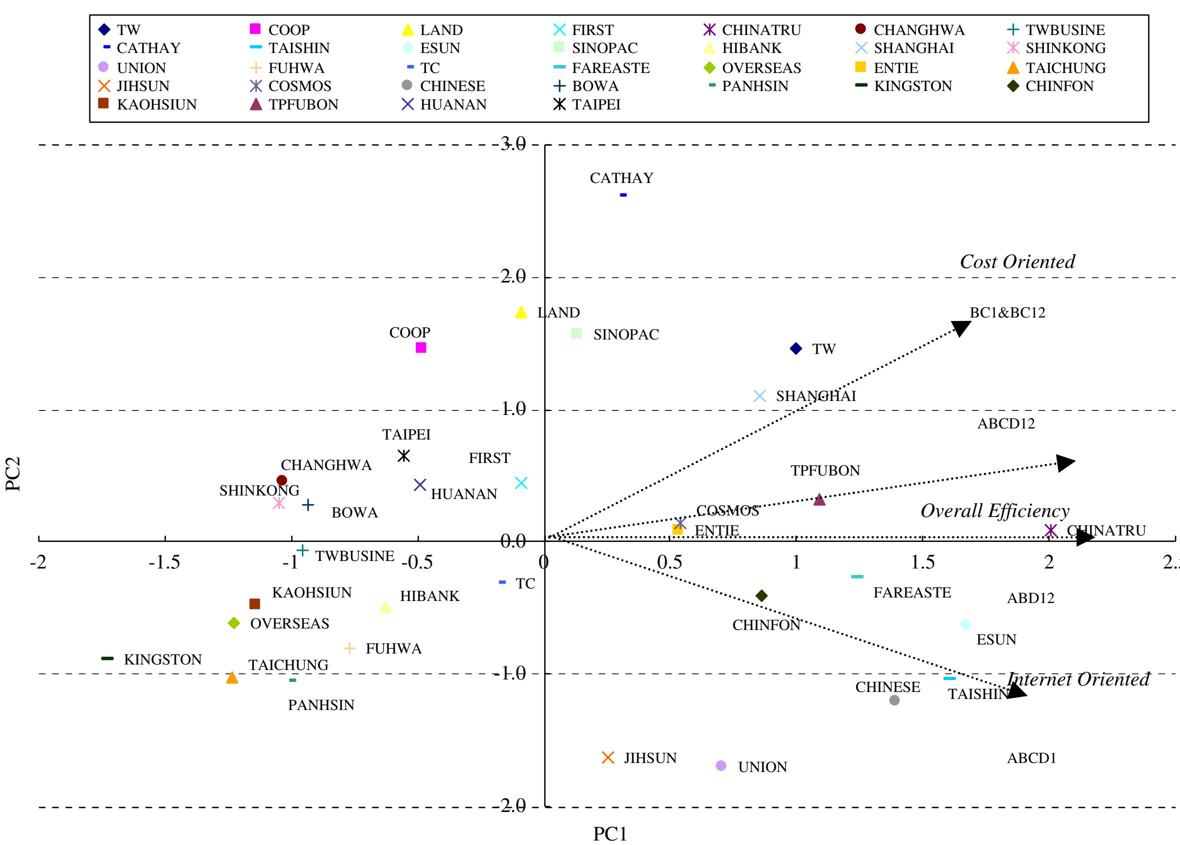

Fig. 2. Plots of principal component loadings (banks).

increases from left to right in this figure, confirming the interpretation of the first principal component as an overall measure of efficiency. Therefore, the top 10 overall efficient banks are Chinatrust Bank (CHINATRU), E. Sun Bank (ESUN), Taishin Bank (TAISHIN), Chinese Bank (CHINESE), Far Eastern Commercial Bank (FAREASTE), Taipei Fubon Bank (TPFUBON), Chin Fon Bank (CHINFON), Shanghai Commercial & Savings Bank (SHANGHAI), Union Bank (UNION), and Cosmos Bank (COSMOS), consecutively. The second principal component was identified as a determinant between the cost oriented and Internet oriented efficiencies. If a bank was located on the top side, this bank only focuses on cost efficiency, and was relatively inefficient by web metrics; the banks on the bottom side represent Internet-efficient banks with relatively less cost efficiency.

Cathay United Bank (CATHAY) is in the top half and is obviously not Internet oriented, as, under the model with the output 2 (web daily reach), its DEA score values do not exceed 20%. Under models relying on output 2, Cathay United Bank, Land Bank (LAND), and Sino Pac Bank (SINOAPC) are progressively weak in web reach. Looking to cost efficiency, two banks located on the B and C vector, Taiwan Bank (TW) and Shanghai Commercial & Savings Bank (SHANGHAI), have higher DEA score values under models with B (operation cost) and C (employees). The bank located on the ABCD1 vector; Taishin Bank (TAISHIN), can be called Internet oriented, as its DEA score values were relatively higher for models with web reach.

Overall, the banks located in Vector I are good in overall measured efficiency and cost efficiency without Internet advantage: Taipei Fubon Bank (TPFUBON), Cathay United Bank (CATHAY), and Lank Bank. Chinatrust Bank (CHINATRU), found near the horizontal, uses both cost and Internet service to their advantage. Beyond it, the banks located in vector IV represent those good in overall measure and also in Web reach: E. Sun Bank (ESUN) and Taishin Bank (TAISHIN). When comparing the PCA results to the DEA complete model, plots of PCA show interrelations between the banks and all 45 combinations using six different variables; the traditional DEA approach considers only one possibility for variables. This study's use of PCA analysis dramatically expands the data explaining the ability of the DEA approach.

5. Conclusions and future research

The banking industry is one of those that have most benefited from the rise of e-commerce, with the Internet considerably changing the channel between client and bank. Nonetheless, there have been very few academic investigations measuring Internet banking performance, especially applying DEA to combined financial data and web metrics. Some studies on performance measurement for the banking industry use the DEA approach with only financial variables. This paper, on the other hand, combines both financial and non-financial variables. This study's major contribution is to construct a framework, combining DEA and PCA approaches, and use it for comprehensive measurement of online banking based on collected financial reports and web metrics. The well-known DEA approach cannot distinguish between efficient companies on its own, but if PCA analysis is added to find differences in business operation, the two can be used to pinpoint the weaknesses and strengths of the 32 banks analyzed. The 32 banks are individually run through the 45 DEA combinations to judge operating orientations. The 45 combinations of DEA model provide for nearly any operational eccentricity, or combination of relative efficiencies. From the efficiency results of the DEA models, it is easy to see the weaknesses and strengths of each firm; PCA analysis unearths the major component at work, helping to complete the picture—in this case, of 32 sample banks trying to use Internet banking to their advantage—and understand their orientations and competitive position better than through a simpler DEA analysis.

There are several limitations to this research: the first is that Internet related data, like e-accounts, transactions conducted and funds transmitted online, and the number of e-commerce related staff, had to be treated as confidential commercial information. Second, website design and associated factors (e.g., user friendliness) of banks' web portals were not considered in this research. Third, this research was limited to domestic banks in Taiwan, and excluded foreign banks or small capital banks in Taiwan in order to ensure that samples and data were studied under the same business and economic environment. Lastly, the research was held back by the intrinsic limitations of DEA: it is well known that DEA is influenced drastically by the sampling numbers, and catching the precise number is extremely important while using it.

This, confidential and thus relatively inaccessible, information, the effect of marketing/design capital in web development, limitations of scope to highly specific business environments, and the limits of DEA itself, are believed, may be limitations to consider and overcome in future studies [31–33].

Appendix A. Raw data and sample bank surveyed in the research.

Raw data and sample bank surveyed in the research is given in Table A1.

Table A1

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Variables (6)	4 Input variables				2 Output variables	
Bank (32)	Total deposits (thousand)	Operating cost (thousand)	Employee (people)	Equipment (thousand)	Revenue (thousand)	Daily reach (million)
Bank of Taiwan	2,131,900,057	59,759,910	6863	4,069,731	63,746,176	84.682
Taiwan Cooperative Bank	1,533,042,886	30,768,156	6256	4,223,103	49,930,000	23.519
Land Bank	1,562,079,895	29,615,576	5746	2,996,643	47,678,879	25.690
First Bank	1,187,301,126	37,555,665	7192	3,258,411	50,439,225	49.043
Chinatrust Commercial Bank	1,240,059,690	31,981,944	7749	4,889,534	76,673,914	142.240
CHANG HWA Bank	1,049,039,538	90,809,518	6091	3,673,803	42,739,548	25.960
Taiwan Business Bank	880,248,138	34,382,186	5005	2,180,423	28,869,907	25.940
Cathay United Bank	794,041,906	43,437,703	4190	3,453,194	48,885,722	13.231
Taishin Bank	669,517,878	70,862,244	8215	3,797,032	61,986,986	105.895
E. SUN Bank	440,482,626	8,723,004	3800	2,025,298	20,944,170	54.143
SinoPac Bank	398,499,164	18,149,621	2171	1,429,232	20,738,613	12.895
Hi Bank	331,994,137	13,903,839	3414	3,894,286	17,231,967	18.826
Shanghai Commercial Bank	340,460,048	10,934,187	1966	1,224,973	18,718,207	29.130
Shin Kong Bank	289,443,446	15,818,494	3583	1,119,751	15,304,005	2.679

Table A1 *(Continued)*

Variables (6)	4 Input variables				2 Output variables	
Bank (32)	Total deposits (thousand)	Operating cost (thousand)	Employee (people)	Equipment (thousand)	Revenue (thousand)	Daily reach (million)
Shanghai Commercial Bank	340,460,048	10,934,187	1966	1,224,973	18,718,207	29.130
Shin Kong Bank	289,443,446	15,818,494	3583	1,119,751	15,304,005	2.679
Union Bank of Taiwan	271,830,619	23,577,635	3639	1,500,157	18,472,810	37.533
Fuhwa Bank	257,446,644	11,859,148	2815	1,051,806	11,981,959	13.421
TC Bank	262,956,769	13,603,919	2962	978,292	15,112,000	14.296
Far Eastern Bank	228,052,878	14,548,275	2339	480,048	16,037,528	17.610
Bank of Overseas Chinese	240,508,918	9,610,933	2152	989,016	9,308,564	8.667
EnTie Bank	246,108,380	14,371,162	2137	568,932	14,493,295	14.333
Taichung Bank	239,123,631	8,819,039	1928	1,403,922	8,616,875	12.450
JihSun Bank	227,550,591	14,099,120	3061	1,238,806	13,866,976	26.192
Cosmos Bank, Taiwan	221,826,026	19,200,440	3471	1,561,905	20,476,506	15.211
The Chinese Bank	179,446,952	13,927,871	2969	183,101	13,369,399	13.542
BOWA Bank	173,753,719	10,919,063	1600	649,833	8,693,172	3.632
Bank of Pan Hsin	146,511,124	5,742,973	1697	568,882	5,942,802	7.438
King's Town Bank	136,153,148	5,144,113	1545	936,929	4,803,926	4.000
Chin Fon Bank	127,566,523	9,329,838	1275	499,387	9,073,000	12.130
Bank of Kaohsiung	117,818,657	3,535,222	848	577,432	4,277,505	4.632
Taipei Fubon Bank	733,726,966	32,082,855	5484	3,308,158	48,095,849	65.520
HUA NAN Bank	1,292,091,422	42,329,833	7738	4,533,511	53,813,396	46.862
International Bank of Taipei	335,761,001	13,842,526	2531	1,425,885	16,730,399	9.270

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