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Full Length Research Paper

Exploring the influence of enterprise resource planning (ERP) implementation on corporate performance using a modified data envelopment analysis (DEA) approach

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The benefit of enterprise resource planning (ERP) system for corporate performance is almost ignored at earlier works. To advance earlier researches, this work employs financial data to explore factors of performance advance by illustrating the association between operation management and ERP installation. A two-stage analysis is made to achieve the aim. Firstly, input-output efficiency of a firm is evaluated based on a modified data envelopment analysis (DEA) approach, which controls the variations of macroeconomic prosperity among sample years. Secondly, exactly how the embedded modules of ERP systems enhance the input-output efficiency of a firm is then explored by performing Tobin regression analysis. Comparing the input-output efficiency between the pre-ERP and post-ERP periods, the input-output efficiency is proved to be higher in the post-ERP period since firms benefit from shorter turnover days of account receivable and inventories, as well as longer unpaid accounts turnover days after installing ERP. In addition, Tobit regression results indicate that acceleration of account collections, reduction of inventory levels and consulting support of leading vendors improve the input-output efficiency of the firms. This finding suggests that operational improvement owing to implementation of ERP systems increases the corporate performance.

Key words: Enterprise resource planning (ERP), leading vendor, Tobit regression, data envelopment analysis (DEA), turnover.

INTRODUCTION

The extent to which enterprise resource planning (ERP) system enhances the corporate performance has seldom been addressed in pertinent literature. By extending the results of previous efforts, this study evaluates input-output efficiency during implementation of ERP by using financial data. The proposed DEA model evaluates sample firms that are implementing ERP systems by attempting to determine which sample firm achieves the largest outputs in the corresponding scale of intermediate and primary inputs. The “production frontier”, the most productive benchmark, is estimated based on the DEA approach. Input-output efficiency can then be determined according to the distance between its data point to the “production frontier”. Input-output efficiency score is thus the quantitative and objective criteria of corporate performance.

In contrast with previous research focusing on questionnaires or cases to describe the features of ERP (Kositanurit et al., 2006; Hsu et al., 2008), this study elucidates four research questions based on the input-output efficiency calculated by the modified DEA approach as an indicator of corporate performance. The first research question examines whether significant input-output efficiency differences occur when a company implements ERP systems. As commercial software packages, ERP systems provide cross-organization integration through embedded business processes, generally comprising several modules, including logistic, procurement, sales, marketing, human resources and finance (Davenport, 1998). The ERP platform supports transaction processing, real-time visibility, and cross-functional business process (Weill and Vitale, 2002). ERP systems are thus expected to enable enterprises to produce a higher output in the corresponding scale of inputs. However, empirical insight into how ERP impacts input-output efficiency is limited. Quantitatively comparing pre-ERP and post-ERP input-output efficiencies is thus of worthwhile interest. The second research question

explores how an ERP system can improve the input-output efficiency of a firm. ERP fosters a paperless environment, provides efficient inventory monitoring and selection), reduces lead time and increases inventory accuracy (Bose et al., 2008). Inventory levels are expected to decrease, while sales per employee are likely to increase up to approximately 50% due to ERP implementation (Schaeffer, 1996). In particular, ERP systems even facilitate other coherent business strategies, including total quality management, supply chain management, and activity-based costing strategies (that is, Lea, 2007; Bose et al., 2008; Tarantilis et al., 2008; Li et al., 2008). Although this study discuss how ERP reforms the operation management of a firm, business owners still do not adequately understand how ERP systems can benefit the performance of a firm. By extending the results of above studies, this investigation examines whether ERP-driven reforms of operation management enhance the input-output efficiency of a firm.

The third research question further elucidates whether firms that implement ERP software packages from leading vendors can more significantly increase input-output efficiency than the software packages of other vendors. Ranganathan and Brown (2006) indicated that leading ERP vendors embed their cumulative knowledge and experiences in their ERP packages, explaining why effective ERP systems are more likely to be implemented out under leading vendor consultation. Given the importance of selecting an ERP vendor, this study examines whether leading ERP vendors contribute to the input-output efficiency of a firm.

The fourth research question ascertains whether electronics firms perform better than those not belonging to the electronics industry, given the importance of implementing ERP among Taiwanese electronics firms. In addition to its robust economy, Taiwan has a globally leading electronics industry as a supplier of computer monitors and PC manufacturing. Owing to tremendous amount of electronics product exports, Taiwanese electronics firms rely more on ERP platforms to integrate sales or purchase orders from global branches than firms not belonging to the electronics industry do. Electronics firms would thus find it more beneficial to implement ERP systems. Comparing improvements in input-output efficiency of electronics firms with those of non-electronics ones reveals the specific roles in which ERP systems play in such an export-oriented industry to which Taiwan electronics firms belong.

To answer the above research questions, this study has the four following objectives. First, based on previous theory, this study compares how pre-ERP and post-ERP periods differ in input-output efficiency. Second, this study examines which domains of operation improvements to attribute to advances in input-output efficiency based on ERP systems. Since such improvements in operation management include the acceleration of account collection from customers, reduction of inventory levels and flexible payments to suppliers, this study attempts to represent improvements in inventory management, accounts receivable management and accounts payable management by using the inventory turnover day, accounts receivable turnover day and accounts payable turnover day, respectively. This study also examines how input-output efficiency and these three turnover day variables are related. Third, this study attempts to determine the importance of leading ERP vendors in terms of elevating the input-output efficiency of firms. Finally, this study compares differences in input-output efficiency improvement between electronics and non-electronics firms belonging to the Taiwanese industry.

The aforementioned objectives of this study are achieved based on two-stage analysis. During the first stage, changes in input-output efficiency after firms implement ERP systems are analyzed based on data envelopment analysis (DEA). By using the DEA approach, Sufian and Habibullah (2009) examined efficiency in a bank for several consecutive years. However, that study did not incorporate the variations of macroeconomic status among sample years. In this study, the sampled firms adopted ERP in different years. In this manner, firm efficiency was likely to vary with macroeconomic conditions. Therefore, the influences of macroeconomic prosperity must be adequately controlled when determining firm efficiency. Banker and Morey (1986) suggested evaluating firm efficiency by considering exogenous input variables and controllable factors individually, owing to at firm-specific inputs, that is, labor, capital and raw materials, are discretionary under managerial control while macroeconomic prosperity factors are not. This study examines the role of uncontrollable macroeconomic prosperity by applying a modified DEA model of Banker and Morey (1986), which involves the use of exogenous variable and gross domestic product (GDP) values.

During the second stage, Tobit regression analysis is performed to regress the input-output efficiency scores on operational improvement indicators in the control of ERP vendor characteristics and industrial factors. Given that these operational improvement indicators include turnover days of inventory, accounts receivable and accounts payable, this study can determine whether a better sale or procurement order operations should be attributed to input-output efficiency improvements after ERP implementation.

Based on 470 firm-year observations of Taiwanese firms that implemented ERP systems, empirical results indicate that ERP systems yields a substantial boost in efficiency. Superior levels of functional integration also appear under ERP implementation. The turnover days of accounts receivable and inventory are reduced, while turnover days of accounts payable are prolonged. Additionally, according to our results, the performance of

firms adopting ERP is negatively correlated with accounts receivable turnover days and inventory turnover days. Since ERP can easily solve the problem of surplus or shortage of inventory in factories, the inventory turnover days can be curtailed after the adoption, leading to a superior performance. Moreover, firms adopting ERP systems can integrate client orders from various branches effectively and reduce the number of accounts receivable turnover days, ultimately increasing input-output efficiency. Furthermore, the performance of ERP-equipped firms is positively related to accounts payable turnover days. Capable of postponing their payment to suppliers after implementing ERP, enterprises can utilize a more flexible cash flow and increase their input-output efficiency.

Hypotheses development

Evaluation of how ERP impacts the input-output efficiency of a firm

ERP systems can integrate all departments, including production, sales, material, quality control, finance management, accounting management and information management. Streamlining their operations makes internal management more efficient and upgrades customer service, ultimately satisfying the requirements of rapidly evolving business operations (Davenport, 1998). Cotteleer and Bendoly (2006) elucidated how ERP fosters operational management by comparing pre-ERP and post-ERP order flows. For companies without ERP systems, before the sales office recognizes their sales, each order must be confirmed through the respective manufacturing/distribution centers (MDCs) to ensure that product commitments are met. Logistics personnel must track inventory across MDCs manually, subsequently incurring significant order delays. Conversely, once a firm adopts an ERP application to replace its outdated seniority system, this ERP formula allows the information system to integrate sales information in various regions (e.g., Asia, Europe and North America) via the Internet, thus streamlining enterprise-level transactions. Importantly, ERP systems facilitate a greater awareness of problems and improve fulfillment lead-time, thus allowing firms to commit to orders in real time from anywhere globally. Therefore, in addition to providing the linkage and integration of various enterprise segments, ERP systems decrease the cost and time of data exchange, likely enhancing firm performance as a result (Hitt et al., 2002; McAfee, 1999). Elaine (1997) even indicated that firms having implemented ERP systems have an increased productivity rate, efficient auto-manufacturing scheduling, unduplicated information, improved data sharing and reduced costs in human resources. ERP systems are thus expected to enable enterprises to produce higher outputs in the corresponding scale of inputs. Restated, ERP can raise the input-output efficiency score compiled by the DEA approach. As for the first research question as to whether substantial differences in performance arise when a company does and does not implement ERP systems, we hypothesize the following:

H_1: Substantial differences in input-output efficiency arise in a firm between pre-ERP and post-ERP era.

Determinants of improved input-output efficiency under ERP systems

Previous studies confer that ERP enables all products to be manufactured and sold in a short operation cycle (Bose et al., 2008). The operational cycle refers to how many days are required for a company to transform purchases of inventory into cash receipts from its eventual sales; in addition, it is equivalent to the inventory turnover days plus accounts receivable turnover days minus accounts payable turnover days. From the operation cycle, we can infer that business consists of inventory management, accounts receivable management and accounts payable management. This section analyzes what factors increase input-output efficiency of firms that implement ERP systems in terms of these three operation management types.

Referring to accounts receivable management, ERP systems can customize the accounts receivable module according to the business processes and collect unpaid customer invoices of credit sales timely. The accounts receivable levels can thus be easily reduced, helping us to avoid large bad debts and reduce the number of accounts receivable collection days. For instance, after Arizona Electric Power Corporation implemented the J. D. Edwards ERP system, the days required to close sales reduced from 38 days to only 9 days, while the work order eased from 30 days to 2.5 days.

Figure 1 displays the average turnover days of Taiwanese firms before and after implementation of ERP systems in our sample firms. According to Figure 1, accounts receivable were reduced from 68 days (two year before implementing ERP) to 52 days (six years after implementing ERP). Our results thus demonstrate that implementing ERP can reduce the number of accounts receivable turnover days, thus improving the operation management of a firm. As for our second research question whether a company enhances input-output efficiency by improving accounts receivable management, we hypothesize the following:

H_{2a}: Reducing the number of accounts receivable turnover days caused by implementing ERP can increase input-output efficiency.

As for inventory management, Stratman and Roth (2002) indicated that ERP systems integrate information of

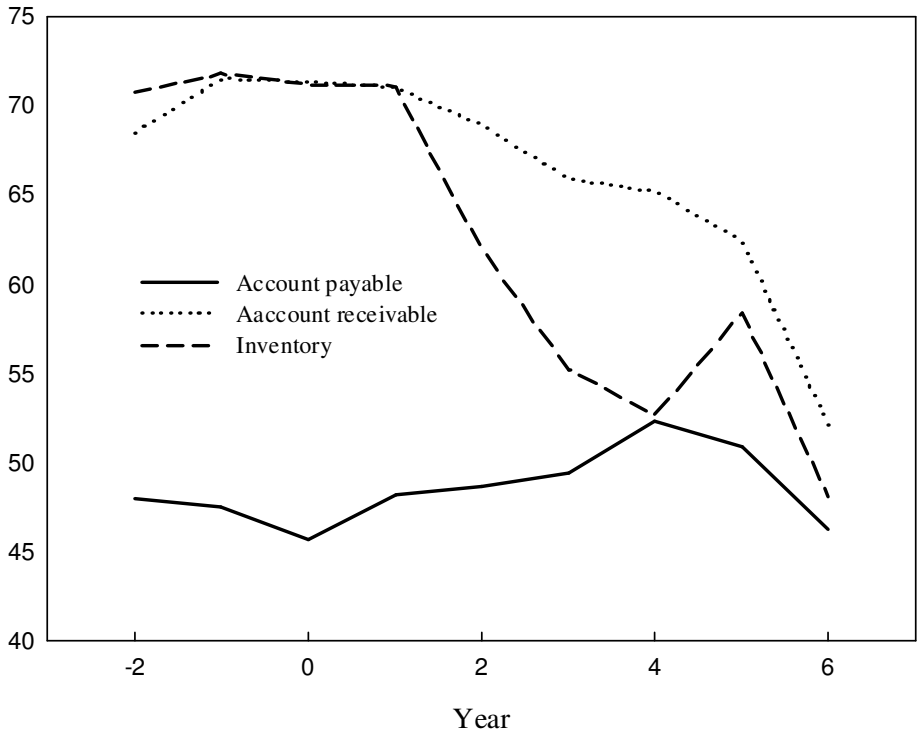

Figure 1. Accounts receivable, accounts payable and inventory turnover days during pre-ERP and post-ERP implementation periods.
The ERP implementation years are set year 0. Negative years represent years prior to the ERP implementation year and positive years represent years subsequent to the ERP implementation year.

production, costs, market forecasting and inventory management, subsequently leading to a balanced production and an increased cash flow and ultimately elevating the market competitiveness of a firm. The American Production and Inventory Control Society issued an analytical report in 1997, indicating that firms with ERP systems have a 60% lower inventory time than its competing rivals. According to Michael (1998), ERP systems increase the accuracy of inventory records to 98.5%, as well as decrease the inventory stock by 20%. Moreover, according to Seifert (1993), ERP systems can also decrease inventory turnover days and subsequently lower inventory costs.

According to Figure 1, inventory turnover days of Taiwanese firms were 70.74 days two year before implementing ERP systems. Following implementation for six years, the systems could reduce the number of inventory turnover days to only 48.03 days. This evidence confirms that implementing ERP can reduce the number of inventory turnover days. Through ERP systems, firms can integrate information systems and create a platform for transparency in data exchange rendering. Consequently, firms can respond to market fluctuations in real time and adjust its inventory, subsequently lowering inventory risks and increasing efficiency across the firm. With the intention of investigating how the number of inventory turnover days affects the efficiency after implementing ERP systems, we hypothesize the following:

H_{2b}: Reducing the number of inventory turnover days caused by implementing ERP can increase input-output efficiency.

ERP systems provide a uniform IT application platform of back-office functions that facilitate technical and business integration (Weill and Vitale, 2002). Gattiker and Goodhue (2000) suggested that ERP systems could enhance data visibility across a firm and increase the accuracy and integration of account payables, salary expenses, and tax payables, thus leading to more efficient enterprise-level transactions. According to Figure 1, accounts payable turnover days of Taiwanese firms increased from 45.65 days during the year in which firms implement an ERP system to 52.32 days after implementing ERP systems for 4 years. A longer turnover day of accounts payables implies a more flexible capital flow. Once the accounts payable turnover days are prolonged by the ERP system, input-output efficiency can be increased by hypothesizing the following:

H_{2c}: Prolonged accounts payable turnover days caused by ERP implementation can increase input-output

Table 1. Profitability indexes of listed companies and electronics corporations in Taiwan

Electronics firm (N=9,126)	Gross margin	Operating income	Pre-tax income	Earnings per share
Mean	732,824	342,382	379,668	2.0271
Standard deviation	4,102,553	2,876,436	3,103,379	4.9624
Total listed firms (N=18,731)				
Mean	723,372	321,796	362,161	1.7045
Standard deviation	3,307,590	2,332,785	2,617,667	4.5385

N=Number of observation

efficiency.

Designing large and complex enterprise integration solutions is extremely difficult owing to the constraints from the current set of legacy applications (Umapathy et al., 2008). ERP implementation projects may have a high probability of failure because enterprises lack experience in implementing ERPs, especially before 2000. For instance, FoxMeyer Drugs and K-Mart Corporations experienced failure in implementing ERP, leading to bankruptcy thereafter. With these two circumstances, firms under ERP systems neither obtained nor reached its efficiency potential (Al-Mashari, 2000; Kumar and Hillegersberg, 2000). Nevertheless, implementing ERP systems takes a considerable amount of time and a substantial amount of capital investment (Bailey, 1999; White et al., 1997; O'Leary, 2000; Escalle et al., 1999). The lack of experienced consultants imposes barriers to successfully implementing ERP systems, explaining why insufficient experience in implementing ERP increased business risks before 2000 (Ausin and Cotteleer, 1999). Given the widely recognized difficulty in implementing ERP, success depends on expert knowledge and the technical skills of third party consultants (Oesterle et al., 2000).

As a great deal of firms begin to implement ERP systems, ERP vendors cumulate more experiences to embed knowledge in process templates by means of packaged application (Scheer et al., 2000). The abundant experiences of leading vendors are likely to decrease the likelihood of failure when implementing ERP. Ranganathan and Brown (2006) asserted that in addition to developing templates based on optimum practices, such experienced vendors also provide preliminary and continuous technical support, frequent upgrades with improved technical and business capabilities, as well as new modules to extend the range of information technology platforms. Thus, the market values were expected to increase for firms that had announced their intentions to install ERP packages provided by a leading vendor (that is, SAP or Oracle) from 1990 to 1998 (Hayes et al., 2001). Namely, investing in an ERP package of a leading vendor increases the likelihood of adopting the optimum practices for a cross-functional business, subsequently increasing the potential benefits of integration. We thus hypothesize the following:

H_3: Leading ERP vendors increase input-output efficiency at a greater degree than other vendors.

Taiwan firms hold the largest share of the global market in IC manufacturing, packaging, and testing, and in 2004, Taiwan's IC design industry was ranked number two in the world (Tsai, 2010). The hi-tech electronics industry in Taiwan has accounted for a significant proportion of the national GDP in recent years. For instance, the production value of the hi-tech industry leaped from 35.3% of total production in 1991 to 54.2% in 2004. This statistic reflects the entry of Taiwan into a hi-tech based economy. Table 1 indicates that standard deviations of profitability indicators, that is, gross income, operating income, pre-tax income and earnings per share, are greater in electronics corporations than those in non-electronics industries. Table 1 also reveals that gross income and pre-tax profit in the Taiwanese electronics industry fluctuates considerably more than they do in non-electronics industries. Given the short product life cycle in the electronics industry, profit variation and business risk also fluctuate much more. Therefore, the electronics industry requires more flexible cash flow management to reduce its risks. As is well known, ERP systems enable the integration of the entire order flow, including production, sales, human resources, research and development and finances. Such systems could facilitate manufacturing management in the electronics industry.

According to Lang and Warfield (1997), the capital market often evaluate electronics industries in higher values by considering non-financially related information such as the implementation of ERP devices. Therefore, this study thus compares how the electronics and non-electronics industry differ in input-output efficiency to investigate whether input-output efficiency of hi-tech electronics industries is superior to that of non-electronics industry after implementing ERP systems. We thus hypothesize the following:

H_4: Electronics and non-electronics industries significantly differ in input-output efficiency after implementing ERP systems.

METHODOLOGY

This study investigates how implementing ERP affects firm input-output efficiency by adopting a two-stage approach, data envelopment analysis (DEA) and Tobit regression. The first stage estimates input-output efficiency by using DEA methods, while the second stage investigates input-output efficiency factors by using a Tobit regression model.

Assessment of input-output efficiency based on DEA

Non-parametric approaches such as DEA, relative to parametric techniques, e.g., stochastic frontier analysis, are characterized by the fact that DEA analysis does not have to assume a particular functional form. Charnes et al. (1978) assumed constant returns to scale when estimating technical efficiency (TE) with the basic DEA method. Most studies select the conventionally adopted DEA method, without considering the exogenous factors to evaluate the input-output efficiency (e.g., Sufian and Habibullah, 2009; Lin et al., 2010). However, our sample firms implemented ERP in different years, explaining why input-output efficiency is likely to vary according to macroeconomic conditions. Importantly, macroeconomic factors must be controlled when estimating the input-output efficiency. In contrast with conventional DEA methods, this study adopts the Banker and Morey (1986) model, which includes the exogenous variable, gross domestic product (GDP) values, to consider this uncontrollable macroeconomic prosperity factor. The inputs are divided into two parts, controllable inputs, that is, labor, capital and raw materials and exogenous inputs (GDP). The DEA model in this study can be formulated as a fractional linear programming problem as Equation (1).

$$
\begin{aligned}
&TE_j = Min\ [\theta - \varepsilon(s_c^{+} + s_F^{+} + s^{-})],\\
&s.t. \sum_{j=1}^{n} \lambda_j X_{i,Cj} + s_C^{+} = \theta X_{CA}, \quad i = 1,2,3,\\
&\sum_{j=1}^{n} \lambda_j X_{Fj} + s_F^{+} = \theta X_{FA},\\
&\sum_{j=1}^{n} \lambda_j Y_j - s^{-} = Y_A,\\
&\lambda_j, s_c^{+}, s_F^{+}, s^{-} \geq 0, \quad j = 1,...,n,
\end{aligned}
\tag{1}
$$

where TE_j denotes TE. θ denotes the maximum proportion of input levels that can be used to procure current output levels for the *j*th DMU; Y_j is the output for the *j*th DMU and $X_{i,cj}$ refers to the *i*th controllable inputs, that is, labor, capital and raw materials for the *j*th DMU; The number of employees, fixed assets, and raw materials are taken as labor, capital and raw material factors. Net sales revenue and pre-tax incomes are taken as output variables[1]; the two input-output efficiency scores can thus be estimated separately. Moreover, X_{Fj} denotes the *j*th exogenous input (GDP) for the *j*th DMU; λ_j represents the weight of the *j*th DMU; and $S^{+}{}_c$, , $S^{+}{}_F$, and S^{-} are the controllable input surplus, the exogenous input surplus, and the output slacks, respectively.

The CRS assumption is only appropriate when all (DMUs) operate on an optimal scale. Imperfect competition, constraints on factors such as finance may prevent DMU from operating at the optimal scale. Previous research suggested extending the CRS DEA model to account for variable returns to scale (VRS) situation (Banker et al., 1984). Use of the CRS specification, when not all DMUs operate on the optimal scale, results in measures of TE biased by scale efficiencies (SE). Use of the VRS specification prevents such an inaccuracy. The CRS linear programming problem can be easily modified to account for VRS by adding the convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$ in Equation (2):

$$
\begin{aligned}
&PTE_j = Min\ [\theta - \varepsilon(s_c^{+} + s_F^{+} + s^{-})],\\
&s.t. \sum_{j=1}^{n} \lambda_j X_{i,Cj} + s_C^{+} = \theta X_{CA},\\
&\sum_{j=1}^{n} \lambda_j X_{Fj} + s_F^{+} = \theta X_{FA},\\
&\sum_{j=1}^{n} \lambda_j Y_j - s^{-} = Y_A,\\
&\sum_{j=1}^{n} \lambda_j = 1,\\
&\lambda_j, s_c^{+}, s_F^{+}, s^{-} \geq 0, \quad j = 1,...,n,
\end{aligned}
\tag{2}
$$

where PTE_j is pure technical efficiency (PTE). The CRS TE measure is decomposed into PTE and SE as the following equation.

$$
TE_j = PTE_j * SE_j . \tag{3}
$$

Scale efficiency is related to the scale of productive facilities. A situation in which the average output of a firm, that is, output per unit input, increases as its input does implies an increasing returns to scale and an improved scale efficiency. However, a situation in which the average output of a firm decreases with an increasing input implies a decreasing returns to scale. Notably, returns to scale remain the same if the average output remains the same with an increasing number of inputs.

Based on the Mann-Whitney U test, this study verifies whether TE, PTE, and SE significantly differ in results before and after implementing ERP systems. The Mann-Whitney U test is a nonparametric statistical method used to verify the efficiency scores of a pair of different observations. Whether TE, PTE, and SE significantly differ after ERP implementation in the sample firms are examined here using statistical methods to validate H_1.

Input-output efficiency determinants using Tobit regressions

This study attempts to identify factors that increase the efficiency of the input-output under ERP systems by applying Tobit regression to

[1] Given that pre-tax incomes are equivalent to net sales minus expenses, net sales and pre-tax incomes are the same output indicator of a firm in terms of profitability. Despite the ability of DEA to evaluate various outputs, net sales and pre-tax incomes should not be treated as multiple outputs. This work evaluates the two efficiency types by applying revenues and pre-tax net incomes as a single output separately.

regress TE, PTE and SE on not only financial turnover factors but also non-financial features as follows:

$$Input-output\ Efficiency = f(ARD, ITD, APD, Vendor, ELE) \quad (4)$$

where TE, SE, and PTE are selected as the input-output efficiency indicators. Notably, *ARD*, *ITD*, and *APD* denote accounts receivable turnover days, inventory turnover days and accounts payable turnover days.

This study examines the significance of the coefficients for these three turnover indicators to validate H_{2a}, H_{2b} and H_{2c}. Additionally, *Vendor* is a dummy variable. 44 and 39% of Taiwanese firms chose SAP and Oracle[2] as ERP package providers from 1998 to 2003. Rather than selecting overseas vendors, the other Taiwanese firms selected local vendors to either implement ERP formula or install ERP by themselves. By using the dummy variable, this study also examines whether ERP firms operating under SAP and Oracle have a superior operation input-output efficiency than that of other vendors, as proposed by H_3. Moreover, *ELE* is another dummy variable.

Notably, variable *ELE* is equal to 1 if the sample firms belong to the electronics industry; otherwise, *ELE* equals 0. This study also applies the electronics industry dummy variable to determine the input-output efficiency difference between electronics and non-electronics industries in order to test H_4.

Data and samples

This study focuses on Taiwanese listed firms that implemented ERP systems from 1998 to 2003. Data from the Financial Supervisory Commission, Taiwan Stock Exchange Market Observation Post System, Central News Agency Clippings System, *Taiwan Economic Journal (TEJ)* database were used, as well as Google searches under the keywords "ERP" or "enterprise resource planning" to identify firms that implement an ERP system. Fifty nine firms were drawn from the above sources as the sample firms in this study.

This study sets ERP implementation years of the 59 sample firms to 0. Negative numbers represent years before ERP implementation, and positive numbers represent years after implementation.

The sample firms implement ERP system in different years from 1998 to 2003, so the collected data of inputs factors, output factors and financial turnover days ranges from 1996 to 2005. Consequently, firms that implemented ERP systems after 2000 lack complete data from year 3 to year 6. Four hundred and seventy firm-year observations are collected in this study. The data of input factor, output factors and financial ratios are collected from Taiwan Economic Journal (*TEJ*) Database.

RESULTS

Comparison of pre-ERP and post-ERP implementation periods in terms of input-output efficiency

Figure 2 illustrates the input-output efficiency (TE, PTE and SE) pattern of all sample firms before and after implementing ERP to estimate input-output efficiency by using both net sales revenue and pre-tax income as the output variables. Figure 2 reveals that TE increases slowly. Moreover, closely examining ERP firms reveals significant advances in SE after implementing ERP. In contrast, PTE continuously declines after implementing ERP, and PTE does not increase until the fifth year after implementing ERP. This may be owing to that the ERP system has interrupted the current balance of the firm. Staff and employees must spend time learning or adapting themselves to ERP systems, subsequently causing a temporary confusion of work divisions and decreasing the input-output efficiency during the initial phase of ERP implementation. This finding corresponds to Ross (1999) in which 15 firms in the production industry was investigated. According to that study, once a firm has invested in ERP systems, the input-output efficiency declines temporarily. Only after two to five years of implementing ERP, visible signs appear of an increased input-output efficiency (Davenport, 2000).

This study further separates the sample firms into electronics firms and non-electronics firms, allowing them to act as two mutually exclusive groups. By doing so, their annual average input-output efficiency trends are illustrated graphically, as shown in Figures 3 and 4, respectively. For electronics firms, the three input-output efficiency patterns are generally the same as that of the full sample firms. According to Figures 3 and 4, TE and SE efficiency improve after ERP implementation, while PTE significantly rebounds only after the sixth year subsequent to ERP implementation. Our results further indicate that the PTE of non-electronics firms is even better before ERP implementation, while that of electronics firms is not. This may be owing to that firms in the electronics industry are much more familiar with information technology (IT) systems than firms in the non-electronics industry. Staff and employees in the electronics industry adapt to the ERP system, which is an IT system, more effectively those in the non-electronics industry. In contrast with the electronics industry, non-electronics firms are more familiar with human interface; in addition, a sudden shift to ERP formula under IT systems may incur substantial confusion. Hence, non-electronics firms are in a more disadvantageous position when attempting to improve PTE through ERP implementation.

Moreover, this study attempts to demonstrate that the pre-ERP and post-ERP stages differ in input-output efficiency by using the Mann-Whitney U test in order to verify the findings. Table 2 summarizes the results of Mann-Whitney U test. The input-output efficiency is also estimated by using pre-tax income as the output variable. According to those results, TE or SE is significantly higher after ERP implementation. Consistent with H_1, the Z statistics under U test also confirm that TE or SE prior to ERP implementation significantly differs from that subsequent to ERP implementation at a significance level

[2] Five leading ERP vendors are SAP, PeopleSoft, Baan, Oracle, and J. D. Edwards (Edmondson and Baker 1997, AMR Research 1999). However, Taiwanese sample firms only select SAP and Oracle vendors, explaining why the vendor variable is coded as one for firms selecting leading vendors, SAP and Oracle.

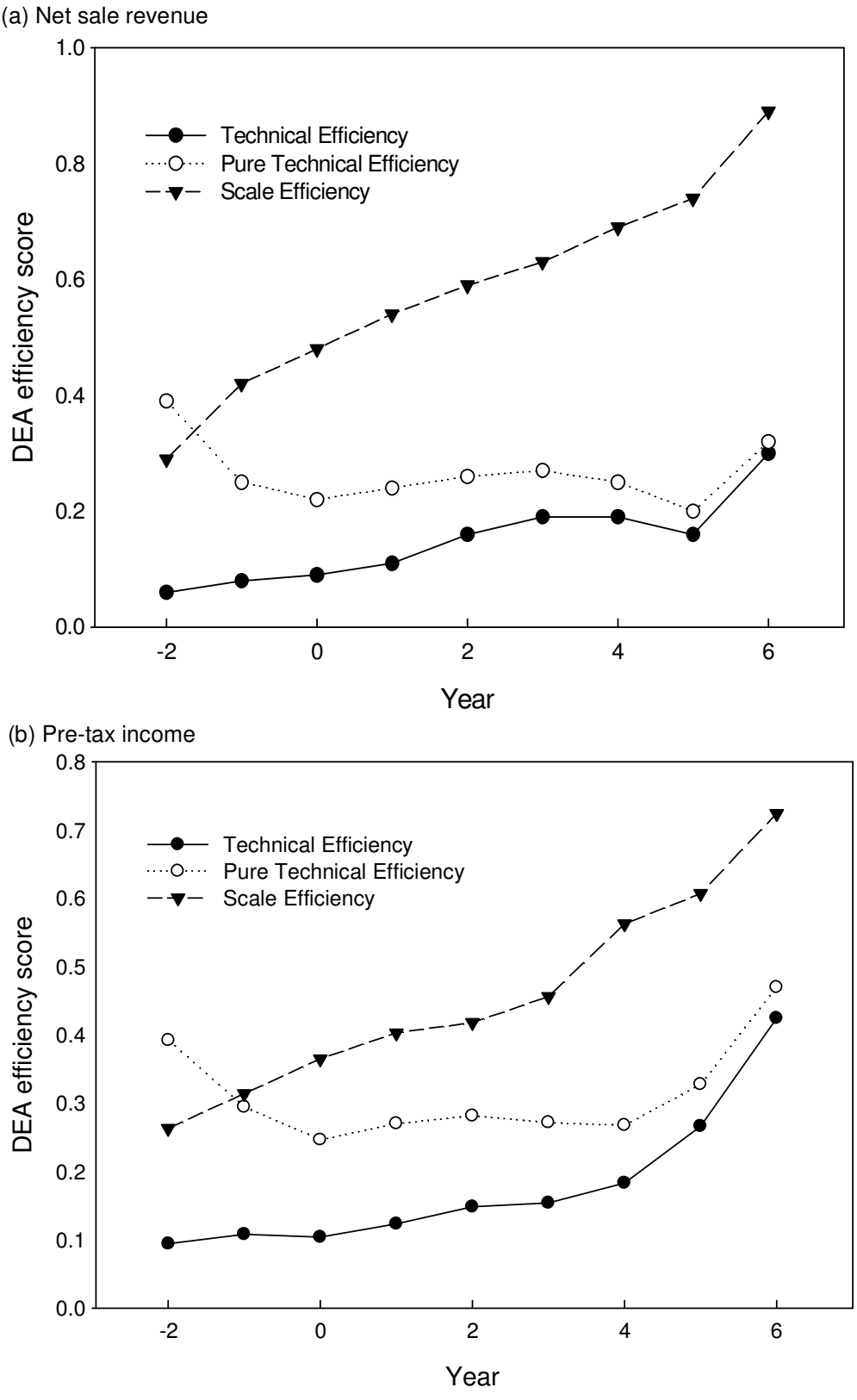

Figure 2. Input-output efficiency of full sample firms before and after ERP implementation. The ERP implementation years are set year 0. Negative years represent years prior to the ERP implementation year and positive years represent years subsequent to the ERP implementation year. Besides, the DEA efficiency scores are evaluated by using (a) net sale revenue and (b) pre-tax income as the output indicators, respectively.

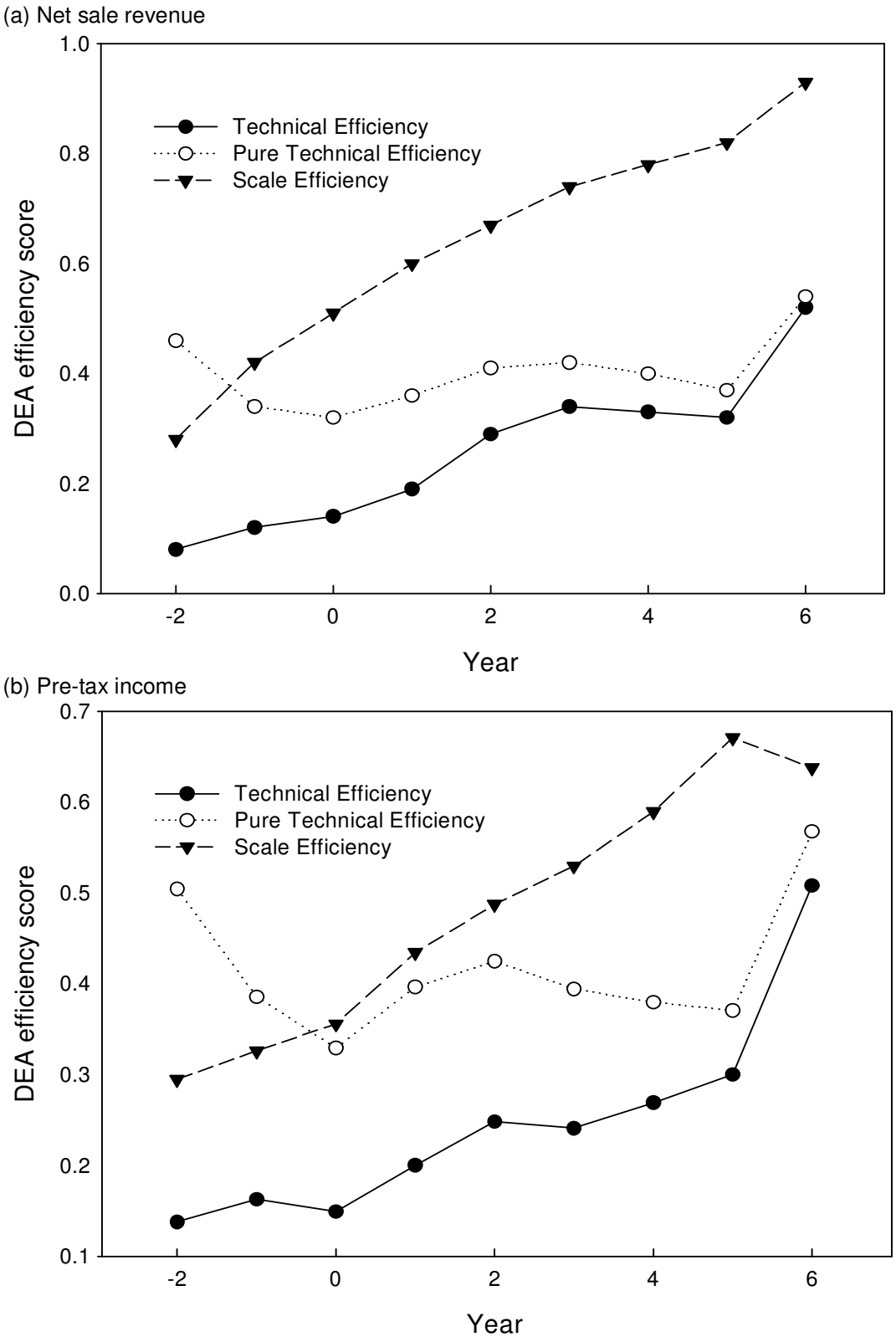

Figure 3. Input-output efficiency of the electronics industry before and after ERP implementation.
The ERP implementation years are set year 0. Negative years represent years prior to the ERP implementation year and positive years represent years subsequent to the ERP implementation year. Besides, the DEA efficiency scores are evaluated by using (a) net sale revenue and (b) pre-tax income as the output indicators, respectively.

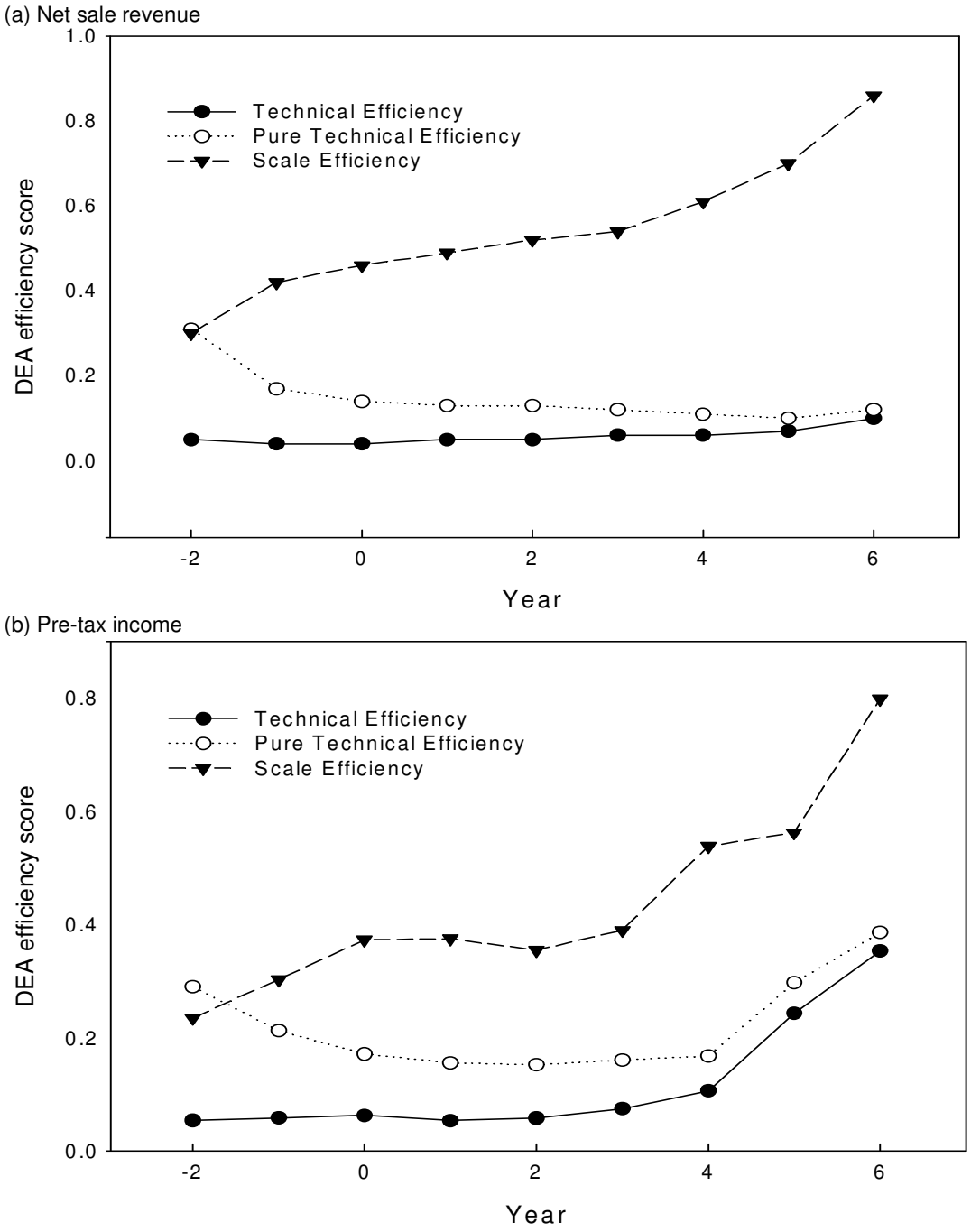

Figure 4. Input-output efficiency of the non-electronics industry before and after ERP implementation. The ERP implementation years are set year 0. Negative years represent years prior to the ERP implementation year and positive years represent years subsequent to the ERP implementation year. Besides, the DEA efficiency scores are evaluated by using (a) net sale revenue and (b) pre-tax income as the output indicators, respectively.

of 1%. Moreover, the input-output efficiency is estimated using both net sale revenue and pre-tax income as the output variables. According to those results, SE obviously increases with ERP implementation. The phenomenon is possibly attributed to the support of ERP technology, through which, firms can develop the optimal scale, subsequently optimizing their resource allocation. Besides, integrating the various divisions in a factory, ERP systems can expand the production scale without additional costs, thus increasing corporate competitiveness.

Table 2. Difference in input-output efficiency between pre-ERP and post-ERP implementation.

Output indicator:	Technical efficiency	Pure technical efficiency	Scale efficiency
Net sale revenue			
Full sample	0.0976	-0.0325	0.2563
Z-statistics	4.6102***	-2.3035**	8.5528***
Electronics	0.1954	0.0350	0.3246
Z-statistics	5.1649***	0.2215	7.4371***
Non-Electronics	0.0159	-0.0859	0.1982
Z-statistics	2.4788***	-2.9847***	4.9109***
Pre-tax income			
Full sample	0.0753	-0.0542	0.1894
Z-statistics	1.0090	-2.4962***	4.0754***
Electronics	0.1031	-0.0267	0.1935
Z-statistics	0.8945	-1.0688	2.7289***
Non-Electronics	0.0532	-0.0745	0.1870
Z-statistics	0.7410	-2.1258**	3.1397***

Firms can adjust the number of finished goods based on the inventory of raw materials, ultimately allow them to elevate SE and raise TE.

As aforementioned, TE subsequent to ERP implementation is significantly superior to TE prior to ERP implementation as we estimate the input-output efficiency by using net sales revenue as the output variable. However, TE is not significantly higher for the input-output efficiency estimation using pre-tax income as the output variable. Notably, net sales revenue and pre-tax income as output indicators differ in terms of estimating TE efficiency owing to that an initial ERP installation typically requires around US $15 million (O'Leary, 2000), and annual expenditures as high as 2 to 3% of the firm revenue (Escalle et al., 1999).

However, its benefits do not start to emerge until after an average of 31 months (O'Leary, 2000). Although ERP elevates the net sales revenue in the first year, the enormous amount of ERP installation expenditures simultaneously reduces the pre-tax income. Consequently, if the pre-tax income is used as the output proxy to determine the DEA input-output efficiency scores, the TE during the initial installation years does not obviously improve than that before ERP implementation.

Tobit regression analysis results

This section describes the determinants of input-output efficiency improvement during ERP implementation periods, ranging from year -2 (two years before ERP implementation) to year 6 (six years after ERP implementation). Table 3 summarizes the Tobit regression analysis results, with TE, PTE and SE as dependent variables, respectively. For the input-output efficiency estimation using both net sale revenue and pre-tax income as the output variables, the TE is significantly associated with the turnover days of inventory, accounts receivable and accounts payable. Table 3 also reveals that the coefficients of accounts receivable turnover days are negative. According to t-statistical results, the coefficients of accounts receivable turnover days are statistically significant at the 1% level. Accounts receivable turnover days appear to negatively explain TE and SE. This finding suggests that during the ERP implementation years, fewer days that a firm spent on receiving their account from the credit sales led to a higher input-output efficiency. With the assistance of ERP systems, firms can integrate information from branch offices distributed over the globe to form a unified set of data, subsequently shortening the credit sale process. Consequently, accounts receivable turnover days decrease after ERP implementation (Figure 1). The input-output efficiency performs better after ERP implementation. Consistent with H_{2a}, the input-output efficiency improvements generated by ERP system should be attributed to the curtailment of accounts receivable turnover days.

The coefficients of inventory turnover days (Table 3) are all negative. According to t-statistical results, the coefficients of inventory turnover days are statistically significant at the 1% level. Input-output efficiency indicators appear to be significantly and negatively related to inventory turnover days. This finding suggests that during the ERP implementation years, fewer days that a firm spent on selling their finished goods inventory after the production process implies a higher input-output efficiency. We can thus infer that ERP systems facilitate the integration of data within several factories and allow raw materials or factory labor inputs to work at optimal levels via the standard inventory management. Firms operating under ERP systems effectively use their

Table 3. Results of input-output efficiency regressed on financial and non-financial factors.

Output indicator	TE		PTE		SE	
	Coefficient	T statistics	Coefficient	T statistics	Coefficient	T statistics
Revenue						
Accounts receivable turnover days	-0.1035	-3.5820***	-0.0778	-1.9782**	-0.2729	-6.1416***
Inventory turnover days	-0.1180	-5.0435***	-0.0992	-3.1237***	-0.2093	-5.8219***
Accounts payable turnover days	0.0927	2.4085**	0.0760	1.4517	0.0352	0.5950
Vendor	4.2517	2.3735**	-9.4302	-3.8754***	22.9976	8.3363***
ELE	13.1288	6.9755***	21.9419	8.5840***	-0.1226	-0.0424
Constant	16.7761	6.4078***	28.6319	8.0536***	78.4444	19.5276***
R2	0.2802		0.2414		0.3420	
Adjusted R2	0.2708		0.2315		0.3335	
Pre-tax income						
Accounts receivable turnover days	-0.1973	-4.3591***	-0.0883	-1.9791**	-0.3330	-5.1724***
Inventory turnover days	-0.2129	-6.1654***	-0.2075	-6.2780***	-0.2611	-5.3603***
Accounts payable turnover days	0.1729	2.9524***	0.1405	2.4029**	0.0718	0.8591
Vendor	-1.4040	-0.4562	-8.6972	-2.8328***	4.5669	1.0404
ELE	4.7800	1.4370	-3.7684	-1.1262	13.1255	2.7594***
Constant	27.5884	6.4583***	49.1809	11.5871***	63.4500	10.4390***
R^2	0.1485		0.1162		0.2236	
Adjusted R^2	0.1375		0.1047		0.2135	

*Significant at the 10% level, **Significant at the 5% level, ***Significant at the 1% level and the dependant variables include TE, PTE and SE (%).

resources, subsequently leading to a significant decline in their average inventory turnover days (Figure 1). Hence, the reduced inventory turnover contributes to the input-output efficiency after ERP implementation. Consistent with H_{2b}, the improved input-output efficiency generated by the ERP system is attributed to the reduction of inventory turnover days.

Table 3 reveals that TE is positively associated with the turnover days of accounts payable. A larger number of days of accounts payable imply a higher input-output efficiency. Since ERP systems enable both the economies of scale and the effective management of firms, firms adopting ERP systems are more likely to be permitted by their suppliers to prolong the period of unpaid account (Figure 1). Hence, the input-output efficiency improves due to a flexible cash flow once firms delay to pay for their procurements. Additionally, the findings concerning how operational progress of accounts payable management impacts firm input-output efficiency are consistent when either profit or revenue related variables are introduced as the output indicators to evaluate the DEA input-output efficiency.

As for non-financial characteristics, the coefficient of leading vendor variable is positive for TE and SE in the input-output efficiency estimation, as determined by using the net sale revenue as the output indicators. Firms adopting SAP or Oracle systems have a significantly higher input-output efficiency than the other firms after implementing ERP. Therefore, we can infer that such rapid growth in input-output efficiency is attributed to the conjoined support from experienced consultant agents. The findings correspond to H_3.

Conversely, the coefficient of leading vendor variable is insignificant for TE and SE when estimating the input-output efficiency, in which pre-tax income is used as the output indicator. This observation is probably owing to the enormous consultant charges of the ERP leading venders during the sample period, that is, from the commencement of ERP implementation to 2005. Pre-tax income equals total sales revenues minus total expenses for enterprises. Although ERP leading vendors elevate the net sale revenue to a greater extent than the other vendors do, the pre-tax income is simultaneously reduced by the larger amount of consultant charges paid to the leading vendors. Consequently, utilizing the pre-tax income as the output proxy makes it impossible to distinguish between firms using leading vendor packages and the firms using other vendor devices in terms of input-output efficiency.

Additionally, the coefficients of electronics industry dummies are significantly positive in Tobit regressions in which TE and PTE are employed as the dependent variables when net sale revenue is taken as the output indicator to estimate input-output efficiency. This finding is the same with SE when pre-tax income is taken as the output indicator. The electronics firms perform superior to non-electronics firms after ERP installation because employees and staff in the electronics industry are more

accustomed to such information technology than those in other industries. The findings of Tobit regressions correspond to the findings of Figures 3 and 4 as earlier mentioned.

Conclusions

Given the relatively little attention paid to the relationship between input-output efficiency advance of firms and the implementation of ERP systems, this study compares pre-ERP and post-ERP periods in terms of input-output efficiency by utilizing the modified data envelop analysis (DEA) of Banker and Morey's (1986), which incorporates exogenous inputs. Empirical results validate our hypotheses, indicating that firms adopting ERP perform superior to firms not adopting ERP across a wide variety of input-output efficiency measures. This finding suggests that ERP systems yield substantial benefits to the firms. Superior levels of functional integration are also apparent under ERP fittings. The turnover days of accounts receivable are reduced from 68 days (two years before ERP implementation) to 52 days (six years after ERP implementation). The turnover days of inventory decline from 70 days (two years before ERP implementation) to 48 days (six years after ERP implementation). Additionally, firms can prolong the turnover days of accounts payable from 45 days (ERP installation year) to 50 days (five years after ERP implementation).

This study further demonstrates that input-output efficiency of a firm is closely related to the turnover days of accounts receivable, inventory and accounts payable. This finding suggests that the functional integration under ERP fittings largely drives the input-output efficiency elevation. Interestingly, a greater progress in input-output efficiency can be made with leading vendor packages (SAP and Oracle) than other vendor packages. Moreover, the boost in input-output efficiency is greater with electronics firms than with non-electronics ones. Above results demonstrate how non-financial factors, differences in industries and proficiency differences of vendors can impact the input-output efficiency of a firm after ERP implementation. Since ERP systems facilitate the integration of overall business operations, e.g., production, sales, human resources, research and development along with finances, such systems coordinate effective management in the electronics industry.

Despite its obvious contributions, this study has certain limitations. This study only monitors the performance of firms for six years after ERP implementation due to a lack of long-term post-implementation data. Future research should analyze in detail how ERP impacts productivity in the long term.

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