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The performance of firms and the attributes of their information systems: A multivariate analysis*

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Abstract

This paper presents a longitudinal analysis of the relations among economic characteristics of the very large US firms listed in the Fortune 500 and the attributes of their information systems (*IS*). These relations are estimated within a multivariate model using *n* economic characteristics in conjunction with *m* *IS* attributes that describe *K* firms during *T* periods. The model and the methodology of this paper can be applied to all firms. However, here we focus on American firms only since the parameters of the model may be dependent on unobserved characteristics of the business, managerial and cultural environment, which may differ across countries and regions. The results suggest that the productivity paradox may result from the failure to properly account for heterogeneity of firms in their use of inputs. Our multivariate model controls for this heterogeneity and classifies the sample into three relatively homogeneous groups. Systematic and positive relations exist between the *IS* attributes and the economic variables of firms within each of these groups. We also estimate the *firm effect*, derived from the firm's economic and *IS* characteristics and serving as an efficiency index of its performance, and demonstrate that firms that are less efficient in their production process overall tend to overinvest in *IS*.

Keywords: Management information systems, firms, multivariate model.

1. Introduction and background

The information system (*IS*) of the firm is a resource that aims to help fulfill two basic needs: a) keeping the organization working, and b) supporting its strategic targets. The perception of *IS* and information technology (*IT*) has undergone a significant conceptual change during the last decade. From tools to record business transactions, *IT* has become (or has at least been perceived to have become) instrumental in pursuing business strategy, in gaining advantages vis-a-vis competitors, and in relations with customers, suppliers and the like. The *IS* should thus reflect two aspects of the firm - its structure and business, on the one hand, and its goals and achievements on the other (see Ahituv, Neumann and Riley, 1994). If the firm's *IS* does not match its structure and business, one cannot expect that it will support its daily operations. Furthermore, it is anticipated that the firm's performance will be correlated, inter alia, to its *IS*. It is reasonable therefore to relate *IS* attributes to those firm variables that reflect its structure, business and accomplishments, particularly its profitability, which is after all the bottom line of business success. Otherwise, why should management decide to invest in *IT*?

Studies on the effectiveness of *IT* investments can be classified into several levels. At the first level researchers investigate the impact of *IT* on macro variables such as GNP, productivity and the like (Roach, 1989, 1991). The lack of revealed impact of *IT* investments found in these studies has given rise to the term "the productivity paradox". At the second level we find studies that attempt to measure the effectiveness of *IT* on an industry. Some results have indicated that *IT* may have an

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impact on firms within an industry. Examples are - the life insurance industry (Harris and Katz, 1989), the valve industry (Weill, 1992) and the banking industry (Banker and Kauffman, 1988, and Alpar and Kim, 1990). However, Ahituv and Giladi (1993) were unable to typify industries by a relationship between *IT* and performance variables. The third level deals with the effectiveness of *IT* on individual firms, and tries to verify whether those investing more in *IT* have anything to gain from it. This level is the focus of the current study.

Most of the empirical support for the claim that *IS* expenditures and investment in information technology improve the performance of firms comes from individual case studies (see, among others, Cron and Sobol, 1983, Porter and Millar, 1985, Clemons and Row, 1988, Wiseman, 1988, Venkatraman and Zaheer, 1990, Banker, Kauffman and Morey, 1990, and Dos Santos and Peffers, 1992). In addition, studies that employ recent firm-level data find that *IS*s have made a substantial contribution to the output of firms (see Brynjolfsson and Hitt, 1993, Lichtenberg, 1993). However, most empirical studies (Ahituv and Giladi, 1993, Kauffman and Weill, 1989, Kauffman and Kriebel, 1988, Dos Santos, Peffers and Mauer, 1993, and Weill, 1992) find very low systematic relations between firm performance and *IS*. For an extensive review of previous studies, see Kauffman and Weill (1989), Dos Santos and Peffers (1993), Dos Santos, Peffers and Mauer (1993), Weill (1992), and Brynjolfsson (1993).

Brynjolfsson (1993) and Brynjolfsson and Hitt (1993) suggest a number of possible reasons for the "productivity paradox", among which are the following.

- Measurement problems: it is hard to isolate and measure the impact of *IT*.
- Organizational survival: in many cases organizations invest in *IT* in order to survive rather than to profit.
- Consumer surplus: in many cases the consumers benefit from a better or cheaper product or service; this would not be reflected in the bottom line of the financial statements.
- Delayed effects: there is a time gap between the investment in *IT* and the fruits engendered from the investment.
- Mismanagement: the investments in *IT* are poorly managed, and therfore are not effective.

Most researchers used regression analysis to correlate *IT* returns (*economic variables* that account for the firm's economic performance) to *IT* investments (*attributes* that represent the *IS* of the firm), employing many forms of models (see, among others, Alpar and Kim, 1990, Ahituv and Giladi, 1993, Dos Santos, Peffers and Mauer, 1993, Brynjolfsson and Kemerer, 1993, and Ahituv, Lipovestky and Tishler, 1996). The major obstacles to understanding the relation between these two sets of variables are (i) the lack of comprehensive microeconomic theory of the *IS* of the firm, (ii) the existence of many (sometimes highly correlated) variables in each of the two sets, preventing the use of a simple statistical model to reveal significant effects of one set on the other, and (iii) the unavailability of reliable price indices for *IS* attributes and, in particular, for an aggregate measure of *IS* expenditure. In principle, the relations between the *IS* attributes and the performance of a firm can be deduced from microeconomic theory by a profit maximization (or cost minimization) process. However, unlike other inputs (labor, energy, etc.), but like management, *IS*s are difficult to quantify or even to define precisely. Therefore, it is impossible, or at least difficult, to employ the standard theoretical model of profit maximization (cost minimization), which uses the prices of all inputs relevant to the production process.

In this paper we concentrate on very large firms, in which the *IT* is essential to even very simple daily activities. Moreover, we confine our analysis to US firms, which we assume operate in a homogeneous environment. We use a multivariate statistical model to approximate the relations among the economic variables and *IS* attributes of firms over time. Multivariate analyses are often employed when researchers need to represent a very large data set by several, easy-to-interpret variables, or when it is necessary to relate a set of variables (rather than a single variable) to other sets of variables. These methods facilitate the identification of effects of key variables of one data set on all, or several, of the variables in the other data sets. Depending on the particular application and the available data, a multivariate method serves either as the first stage of the quantitative analysis (in which case it is a linear approximation for a more complicated nonlinear model), or as the true representation of the theoretical model that one needs to estimate. There are numerous examples of the ways multivariate methods have been used in the past (see, for example, Harman, 1976, Timm, 1975, Tishler, Dvir, Shenhar and Lipovetsky, 1996, Tishler and Lipovestky, 1996, Fornell, 1982, Green, 1978, Dillon and Goldstein, 1984 and Cliff, 1987). The model that is used in this study is only a first-order approximation to the true (albeit unknown) theoretical model that relates the performance of the firm (as expressed by its profits, sales, etc.) to its use of inputs. Thus, our estimation results should be considered only as indications of the true relationship among the *IS* attributes and the economic variables that represent the firm's economic performance. Though the model and the methodology that we use can be applied to all firms, the reasons for focusing the analysis on American firms are as follows. First, the parameters of the model may be generally dependent on characteristics of the business, managerial and cultural environment in which the firm operates, which may vary substantially across countries and regions. The availability and use of *IT* and the effect of *IT* on business success depend on the stage and rate of development of the region in which the firm operates, on the prevailing legal system, management culture, and other variables that characterize the business culture of the firm's immediate environment. Since it is difficult to quantify many of the business environment variables across regions, most applied studies focus, as we do here, on a particular region or country. Second, we were able to obtain sufficient detailed data on *IT* investment and on measures of performance of US and Israeli firms only. Since the business environment and culture of these two countries are very different, we analyze and present here only the US data. Analysis of the Israeli data will be the subject of future research.

The model used in this paper approximates a four-way matrix Z, consisting of n economic variables indexed by $i=1,...,n$, in conjunction with m *IS* attributes indexed by $j=1,...,m$, by K firms indexed by $k=1,...,K$, at times $t=1,...,T$. In order to reveal the relations between the economic variables and the *IS* attributes of the firms, we approximate the evaluations Z_{ijkt} by a function of several families of parameters: $a_1,a_2,...,a_n$ of the n economic variables in order to rank them by their importance to the *IS* of the firm; weights $b_1,b_2,...,b_m$ for the m *IS* attributes which describe the relative importance and significance of these attributes to the firm; weights $c_1,c_2,...,c_K$ for individual firms which can be used to classify them into groups with similar economic and *IS* structure; and weights $d_1,...,d_T$ to account for the effect of time (overall conditions of the economy).

The full sample of firms that we analyzed showed a high and positive overall correlation between *IS* attributes and economic variables that represent the performance of firms, leading us to suggest that the "productivity paradox" (see Brynjolfsson, 1993) may be due to the failure to account properly for the heterogeneity of firms in their use of inputs (labor, *IS*, etc.). The results show that highly profitable firms are efficient in their use of all inputs - labor and *IS*; they exhibit the highest average per employee profits and sales. Firms that are less efficient in the use of inputs exhibit poor performance, a natural result that should not be attributed solely to the *IS*. The multivariate model controls for the heterogeneity among firms and classifies the sample into three relatively homogeneous groups. The overall, as well as pairwise, correlations between *IS* attributes and the economic variables are very high within each group.

This paper is organized as follows. Section 2 describes the data and presents initial analyses of the relations among *IS* attributes and economic variables that are consistent with the "productivity paradox". The model and the estimation methods - which disprove the "productivity paradox" - are developed in Section 3. Estimation results are presented and analyzed in Section 4. The classification of the firms in the sample according to their *IS* attributes and economic variables is given in Section 5. Section 6 summarizes the results and provides some concluding remarks.

2. Data

Data on several economic variables and on various *IS* attributes for the years 1989, 1990 and 1991 were collected from various issues of Fortune and Computerworld. The economic variables that describe the overall activity of the firm at time *t* are: sales[1] (*S*); change in sales from the previous year (*ΔS*); profits[2] (*P*); change in profits from the previous year (*ΔP*); assets[3] (*A*); stockholder equity[4] in the firm (*E*); and number of employees (*L*). The attributes that describe the *IS* structure of the firm are: total *IS* budget (*B*); value of the main processor that the firm owns (*C*); the amounts, from the *IS* budget, that were spent on wages (*W*), and on employee training (*T*); and the number of *PC*s used by the firm (*Q*). For ease of exposition, we organize the economic variables in the vector

$$F = (S, \Delta S, P, \Delta P, A, E, L),$$

and the *IS* attributes in the vector

$$M = (B, C, W, T, Q).$$

The data for all the above-mentioned variables were available for 43, 92, and 80 firms in 1989, 1990 and 1991, respectively. Data for 31 firms were available for both 1989 and 1990, but not for 1991, and data for 43 firms were available for both 1990 and 1991, but not for 1989. Data were available for the entire sample period 1989-1991 for 20 firms only. In the following analysis, we concentrate on the 20 firms with complete data for 1989-1991. We present results for each year separately, as well as for pairs of years (1989-1990, 1990-1991). Tables 1 and 2 present summary statistics for the twenty firms. Table 1 summarizes the 1991 data set for all 20 firms together. Table 2 presents the 1991 data for individual firms (the data for 1989 and 1990 are similar to the 1991 data, so we do not present them here).

Tables 1 and 2 show large variability in firm size, technology and use of *IS*. The main source of heterogeneity among the firms is *firm size*. Thus, to allow a meaningful interpretation of the relations among the *IS* and economic variables across firms, and to control for firm size, we normalized the data, dividing each economic and *IS* variable by the number of employees in the firm. Table 3 presents the pairwise correlations between the normalized economic and *IS* variables.

Generally, the correlations in Table 3 are small; however, about half of them are greater than 0.25, and some are as high as 0.65 (sales per employee with expenditure per employee on training employees in *IS*), or even 0.69 (sales per employee with the value per employee of the firm's main processor). Of the five *IS* variables considered, value of the firm's main processor correlates most closely with the economic variables of the firm.

It is worth noting that the simple correlations reported in Table 3 (in which all variables are normalized by the number of employees) are slightly higher than those for the same pairs of variables normalized by sales. The normalization by the number of employees is meaningful for all types of

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1 Sales of consolidated subsidiaries and discontinued operations were included. Sales figures are for the year ending December 31 and do not include taxes collected.

2 Profits are after tax and after extraordinary credits or charges.

3 Assets are assets at the company's fiscal year end.

4 Stockholder equity is the sum of capital stock, surplus, and retired earnings at the company's fiscal year end.

Table 1: Summary of the 1991 Data (20 Firms)

		Minimum	Average	Maximum
Economic Variables:				
S:	Sales ($ million)	2754	12492	57242
ΔS:	Change in sales ($ million)	-700	654	3449
P:	Profits ($ million)	-275	615	2122
ΔP:	Change in profit ($ million)	-1535	-50	377
A:	Assets ($ million)	2363	18734	106435
E:	Equity ($ million)	952	4689	14188
L:	Employees (thousands)	8	83	450
IS Attributes:				
B:	*IS* budget ($ million)	60	515	1600
C:	Value of main processor ($ million)	1	188	687
W:	Expenditure on wages in *B* ($ million)	28	220	848
T:	Expenditure on training in *B* ($ million)	1	16	40
Q:	Number of PCs (thousands)	6	59	350

Table 2: 1991 Data (20 Firms)

Firm	Sales ($10^6)	Employees (1000)	Profits ($10^6)	Assets ($10^6)	IS Budget ($10^6)	PCs (1000)
1. Abbott Laboratories	6922	46	1089	6255	170	15
2. Ameritech Corp.	10818	74	1166	22290	561	66
3. AMR Corp.	12993	116	-240	16208	1091	118
4. Banc One Corp.	4142	28	530	46293	293	30
5. Bell Atlantic Corp.	12280	76	-223	27882	750	70
6. Dow Chemical Co.	19305	62	942	24727	400	32
7. Federal Express Corp.	7688	82	6	5673	360	60
8. Gillette Co.	4706	31	427	3887	120	9
9. Grumman Corp.	4038	24	99	2363	153	18
10. GTE Corp.	21823	162	1580	42437	800	60
11. Inland Steel Industries Inc.	3405	19	-275	2698	60	6
12. Martin Marietta Corp.	6102	61	313	3897	301	24
13. McDonnell Douglas Corp.	18718	109	423	14841	683	75
14. MCI Communications Co.	8439	28	551	8834	460	34
15. Merck & Co.	8765	38	2122	9499	160	15
16. Northeast Utilities	2754	8	237	6782	73	6
17. Northrop Corp.	5706	36	201	3128	248	24
18. Sears, Roebuck & Co.	57242	450	1279	106435	1233	350
19. The Boeing Co.	29314	159	1567	15784	1600	123
20. The Dun & Bradstreet Co.	4685	59	509	4777	778	50

Table 3: Simple Correlations - 1991 Data (20 Firms)

	Economic Variables					
IS Attributes	Sales *(S/L)*	ΔSales *(ΔS/L)*	Profits *(P/L)*	ΔProfits *(ΔP/L)*	Assets *(A/L)*	Equity *(E/L)*
IS Budget *(B/L)*	0.26	0.26	0.07	0.14	0.30	0.26
Main Processor *(C/L)*	0.69	0.35	0.32	0.16	0.33	0.66
Wages in *IS (W/L)*	0.32	0.24	0.16	0.22	0.12	0.25
Training in *IS (T/L)*	0.65	0.24	0.29	0.10	0.37	0.51
Number of PCs *(Q/L)*	0.09	0.24	-0.10	0.08	0.38	0.16

Note: All variables are normalized by the number of employees.

firms. However, the variable sales is not consistently defined for commercial (as opposed to industrial) firms. As an extreme example, consider banks, for which the term sales (or revenues) does not reflect the economic sense of output (see Alpar and Kim, 1990, on this issue). Thus, in this paper we represent firm size by the number of employees. However, the main results in this paper are unchanged when firm size is represented by sales.

The effect of the *IS* attributes on the performance of firms, as expressed by the economic variables, cannot be well approximated by a simple regression model - the model which is implied by the simple correlations in Table 3. Moreover, the effect of *IS* attributes on firm performance cannot be deduced from a more general multiple regression model. The regressions (for 1991) of sales, change in sales, profits and change in profits on all five *IS* attributes considered are presented in Table 4.

Table 4: Regressions of Economic Variables on *IS* Attributes (20 Firms, 1991 Data)

	Dependent Variables (Economic Variables)			
Regressors *(IS Attributes)*	Sales *(S/L)*	ΔSales *(ΔS/L)*	Profits *(P/L)*	ΔProfits *(ΔP/L)*
Constant	0.17 (5.6)	0.00 (0.2)	0.02 (1.7)	-0.00 (-0.5)
IS Budget *(B/L)*	-13.55 (-1.4)	0.47 (0.2)	-1.52 (-0.5)	-0.46 (-0.3)
Processor *(C/L)*	11.13 (2.2)	1.39 (0.9)	1.19 (0.8)	0.20 (0.3)
IS Wages *(W/L)*	13.17 (0.8)	-0.70 (-0.2)	3.24 (0.7)	1.88 (0.8)
IS Training *(T/L)*	178.82 (2.2)	-4.90 (-0.2)	16.23 (0.6)	-2.23 (-0.2)
Number of PCs *(Q/L)*	-0.03 (-0.5)	0.00 (0.2)	-0.02 (-0.8)	-0.00 (-0.1)
R^2	0.67	0.13	0.23	0.07
R_{dj}	0.55	0.00	0.00	0.00

Notes: t-statistics are in parentheses.
All variables are normalized by the number of employees.

Clearly, sales is the only economic variable that can be explained to some extent by the *IS* attributes. Furthermore, the estimated parameters are generally insignificant and in several cases, negative. Thus, the estimates of the regressions cannot identify the above-mentioned marginal effects (See also Ahituv, Lipovetsky and Tishler, 1996, on this issue). Therefore, in the next section we use multivariate analysis and redefine the relations between the *IS* attributes and the economic variables.

3. The model and estimation methods

The data displayed in Tables 1 and 2 are very heterogeneous, in particular with respect to the *IS* attributes. The imperative to control for this heterogeneity in order to develop a relatively simple model to approximate reality is executed as follows. Let

$$Z_{ijkt} = \left(F_i / M_j\right)_{kt}, \qquad (1)$$

where Z_{ijkt} denotes the ratio of the *i*th economic variable (in the vector *F*) to the *j*th *IS* attribute (in the vector *M*) of firm *k* at time *t*. Thus, Z_{ijkt} denotes the "intensity" of the economic variable *i* in the firm's *IS* attribute *j*. This formulation controls both for firm size and for the heterogeneity of the use of *IS* across firms, postulating a variant of a "fixed proportions" technology of the *IS* attributes. One can perceive the data Z_{ijkt} as follows. First, consider a two- dimensional $(n'm)$ matrix Z^{kt} for a given firm *k* at a given time period *t*. The *i*th row presents the *i*th (in its location in the vector *F*) economic variable, divided by each of the *m IS* attributes in the vector *M*. To allow a meaningful comparison among the *m* elements of the *i*th row of Z^{kt}, we divide each element in Z^{kt}, for each period *t*, by the square root of the second moment of this *i*th variable across all *K* firms. This normalization ensures that all elements in Z^{kt}, for all *t*, exhibit the same unit of measurement and a uniform variance; i.e., the values of the parameters of our model (see formula 2) can easily be compared. Augmenting the *K* matrices Z^{kt} (one for each *k*, $k=1,\ldots,K$) yields the cubic $(n'm'K)$ matrix, Z^t. The matrix Z^t contains information on all the ratios (F_i/M_j) for all *n* economic variables and *m IS* attributes across all *K* firms, for a particular year *t* (t=1989, 1990, 1991). The four-way matrix Z T (Z_{ijkt}) is obtained by augmenting Z^t across all *T* time periods. Now we can specify the model using a data-generation process that determines Z_{ijkt}, and a method to estimate its parameters. Clearly, our model is only a first-order approximation of a true (unknown) theoretical model that relates the performance of the firm to its use of all inputs. Thus, estimation results should be considered only as indicative of the true relationships among the IS attributes and the economic variables.

Consider the four-way matrix *Z* and its approximation by the product of four vectors, *a, b, c,* and *d*,

$$Z_{ijkt} = \lambda a_i b_j c_k d_t + \varepsilon_{ijkt}, \qquad (2)$$

where $i=1,\ldots,n;\ j=1,\ldots,m;\ k = 1,\ldots,K;\ t = 1,\ldots,T$. λ is a normalizing constant and ε_{ijkt} is an error term with mean zero. The interpretation of (2) for our data is as follows. The parameters a_i denote the effect of the *i*th economic variable; b_j is the effect of the reciprocal of the *j*th *IS* attribute; c_k is the firm effect; and d_t stands for the year effect.

Suppose that we are given data on Z_{ijkt} and wish to estimate the vectors of the constant parameters *a, b, c* and *d*. Let the objective function be

$$S = \sum_{i,j,k,t} \varepsilon_{ijkt}^2 = \sum_{i,j,k,t} \left(Z_{ijkt} - \lambda a_i b_j c_k d_t\right)^2. \qquad (3)$$

Minimization of *S* in (3), subject to the normalizations

$$\sum_i a_i^2 = \sum_j b_j^2 = \sum_k c_k^2 = \sum_t d_t^2 = 1, \qquad (4)$$

yields the following system of nonlinear equations

$$\sum_{j,k,t} Z_{ijkt}\, b_j\, c_k\, d_t = \lambda a_i, \quad i = 1,\ldots,n; \qquad (5a)$$

$$\sum_{i,k,t} Z_{ijkt}\, a_i\, c_k\, d_t = \lambda b_j, \quad j = 1,\ldots,m; \qquad (5b)$$

$$\sum_{i,j,t} Z_{ijkt}\, a_i\, b_j\, d_t = \lambda c_k, \quad k = 1,\ldots,K; \qquad (5c)$$

$$\sum_{i,j,k} Z_{ijkt}\, a_i\, b_j\, c_k = \lambda d_t, \quad t = 1,\ldots,T; \qquad (5d)$$

$$\sum_{i,j,k,t} Z_{ijkt}\, a_i\, b_j\, c_k\, d_t = \lambda. \qquad (5e)$$

The analytical, as well as the numerical solution can be simplified by substituting out one of the vectors *(a, b, c* or *d)* in (5), preferably the vector that includes the greatest number of components. For example, let

$$K = \max\,(n, m, K, T). \qquad (6)$$

Substitution of (5c) into (5a), (5b) and (5d) yields the following nonlinear eigenvector problem

$$\begin{bmatrix} H_{b'd}\, H_{bd} & 0 & 0 \\ 0 & H_{a'd}\, H_{ad} & 0 \\ 0 & 0 & H_{a'b}\, H_{ab} \end{bmatrix} \begin{bmatrix} a \\ b \\ d \end{bmatrix} = \lambda^2 \begin{bmatrix} a \\ b \\ d \end{bmatrix}, \qquad (7)$$

where

$$(H_{bd})_{ki} = \sum_{j,t} Z_{ijkt}\, b_j\, d_t, \quad i = 1,\ldots,n;\ k = 1,\ldots,K, \qquad (8a)$$

$$(H_{ad})_{kj} = \sum_{i,t} Z_{ijkt}\, a_i\, d_t, \quad j = 1,\ldots,m;\ k = 1,\ldots,K, \qquad (8b)$$

$$(H_{ab})_{kt} = \sum_{i,j} Z_{ijkt}\, a_i\, b_j, \quad t = 1,\ldots,T;\ k = 1,\ldots,K. \qquad (8c)$$

The products of the matrices H in the left-hand side of formula (7) form the matrices of second moments of the initial data in the matrix Z (see formula 2) averaged in different directions with the weights of the respective vectors in (8a), (8b) and (8c).

Estimation of a, b, c and d in (2), which is equivalent to solving formula (7) for the maximal eigenvalue λ^2, requires a nonlinear iterative optimization method. Several methods to solve problems such as formula (7) are analyzed in Lipovetsky and Tishler (1994). Here, we use the Gauss-Seidel procedure, as follows. We obtain initial values for a, b and d (the uniform vectors, for example). Using these values, we compute the left-hand sides of (8a), (8b) and (8c). We then solve (7) as an eigenvector problem and, for the maximal λ^2, obtain new estimates for a, b and d. This process is repeated until convergence is achieved (that is, when a, b and d change from one iteration to the next by no more than a predetermined small amount). Finally, given the optimal *a*, *b* and *d*, we obtain the optimal *c* from formula (5c). The statistical properties of these estimates are found in Amemiya (1983), which derives, among other properties, their asymptotic distribution. In particular, one possible measure of the goodness of fit of our model can be derived as follows. Using the objective function (3), the normalization (4) and the first-order condition (5e), it can be shown that, at the optimum,

$$S = \sum_{i,j,k,t} Z_{ijkt}^2 - \lambda^2, \qquad (9)$$

where λ is the normalizing constant in formula (2). Thus, we define the squared correlation coefficient for (2) by

$$R^2 = \lambda^2 / \left(\sum_{i,j,k,t} Z_{ijkt}^2 \right) \qquad (10)$$

which obeys $0 \leq R^2 \leq 1$

Finally, it may be more intuitive to postulate the process that generates the measurements Z_{ijkt} (see formula (2)) as

$$Z_{ijkt} = \lambda \, \theta_{ij} c_k d_t + \varepsilon_{ijkt}, \qquad (11)$$

and estimate the three-dimensional problem (11) as in Lipovetsky and Tishler (1994). However, the *nm*-element vector θ may be well approximated by the *n*-element vector *a* and the *m*-element vector *b* as follows:

$$\theta_{ij} = a_i b_j , \quad i = 1,\ldots,n; \quad j = 1,\ldots,m, \qquad (12)$$

which leads to the four-dimensional problem described in (2). Our estimates of formula (11) are very similar to those obtained by formula (2), so we do not present them here.

4. Estimation results

Table 5 presents the estimation results for the effect of the economic variables $(a_1,\ldots a_7)$ and the (reciprocal) effect of the *IS* attributes $(b_1,\ldots,b_5)$ for 1989, 1990, and 1991 separately (that is, d_t in formula (2) equals one, which implies a relatively simple three-way optimization problem, instead of the more complicated four-way optimization problem (7)). The results are reported for the set of 20 firms for which we have data covering 1989-1991, and for the largest number of firms in each year separately. Table 6 presents the estimates of *a*, *b* and *d* obtained by estimation over the entire period (1989-1991), and over 1989-1990 and 1990-1991 separately.

The estimation results of *a* and *b* for two years together, or for the entire period (using four-way matrices), are very similar to those obtained from the data of each year separately (using three-way matrices). The data exhibit a high degree of multicollinearity, which manifests itself in the similarity of the values for the components of *a* and *b* (with the exception of a_4).

Note that the economic variables most important for determining Z_{ijkt} (which is the intensity in the firm of each *IS* attribute) are sales (given by a_1) and equity (given by a_6). The change of profits (given by a_4) is the least important, possibly because of the high volatility of this variable over time, compared to the greater stability of the other variables described in Table 1. The values of $1/b_2$ and $1/b_4$ are usually somewhat larger than the reciprocals of b_1, b_3 and b_5; that is, of all the *IS* attributes that we consider here, the value of the firm's main processor (corresponding to $1/b_2$) and the amount spent on training employees in *IS* (corresponding to $1/b_4$) are best related to the economic variables that we use in this study. It is worth noting that the strong and positive relations between the pair of *IS* attributes, main processor and training in *IS*, and the pair of economic variables sales and equity are also evident from the pairwise correlations among these variables (see Table 3). Thus, the results of model (2) are consistent with those obtained by direct observation of the raw data. As noted earlier, the use of formula (11), which amounts to an estimation of 35 θ_{ij}s instead of the 7 a_is and 5 b_js, yielded results that are very close to the products $a_i\, b_j$ reported in Tables 5 and 6.

The estimated year effect, *d*, is 0.35 for 1989, 0.36 for 1990 and 0.29 for 1991 (see Table 6). Thus, 1991 has the least effect on the estimate of *a*, *b* and *c*.

Estimation results for *c*, the *firm effect* on the intensity of the *IS* attributes on the firm's variables, can, however, be quite different when obtained by estimation with a four-way matrix for 1989-1991 (or 1989-1990, or 1990-1991) as compared to estimation for each year separately (by a three-way matrix). In other words, the combined estimation of *c* using a four-way matrix over 1989-1991 avoids the random annual fluctuations in profits or sales on the long-run estimate of the *mean firm effect*. Table 7 presents the estimate of *c*, the *firm effect*, for the firms listed in Table 2.

Table 7 shows, for example, that the estimates of Martin Marietta Corp. and of MCI Communication Corp. are very robust across 1989-1991. However, those of Abbott Laboratories and of Inland Steel Industries Inc. are very different across years. The high variability in *c*, the *firm effect*, for Inland Steel Industries Inc. stems from the large decrease in its sales in 1991 ($3405 million) compared to 1990 ($3870 million) and to 1989 ($4147 million). Similarly, this firm exhibits a marked decline in profits during the same period. However, the interpretation of *c* as the long-run firm effect

Table 5: Estimation Results for *a* and *b*: Three-Way Matrices

	Estimate for	1989		1990		1991	
		20 Firms	43 Firms	20 Firms	92 Firms	20 Firms	80 Firms
	Economic Variables						
a_1	S	0.200	0.212	0.192	0.167	0.188	0.167
a_2	ΔS	0.158	0.140	0.143	0.128	0.106	0.136
a_3	P	0.171	0.167	0.158	0.165	0.150	0.159
a_4	ΔP	-0.075	-0.090	-0.044	0.084	0.003	0.073
a_5	A	0.166	0.175	0.173	0.139	0.177	0.134
a_6	E	0.195	0.201	0.191	0.168	0.194	0.177
a_7	L	0.185	0.195	0.186	0.149	0.182	0.155
	IS Attributes						
b_1	B	0.204	0.216	0.211	0.225	0.238	0.221
b_2	C	0.206	0.198	0.194	0.207	0.120	0.168
b_3	W	0.212	0.224	0.209	0.219	0.233	0.221
b_4	T	0.181	0.171	0.182	0.158	0.169	0.190
b_5	Q	0.197	0.191	0.204	0.192	0.240	0.200
D_1	1989	1	1	-	-	-	-
D_2	1990	-	-	1	1	-	-
D_3	1991	-	-	-	-	1	1

Note: The definitions of the variables are given in Section 2 and in Table 1.
For convenience we set: $a_1+...+a_7 = b_1+...+b_5 = d_1+d_2+d_3 = 1$.

Table 6: Estimation Results for *a*, *b* and *d*: Four-Way Matrices

	Estimate for	Three Years 1989-1991	Two-Year Periods 1989-1990		1990-1991	
		20 Firms	20 Firms	31 Firms	20 Firms	43 Firms
	Economic Variables					
a_1	S	0.200	0.196	0.190	0.194	0.167
a_2	ΔS	0.123	0.144	0.088	0.119	0.138
a_3	P	0.155	0.162	0.178	0.152	0.157
a_4	ΔP	-0.045	-0.052	0.002	-0.026	0.051
a_5	A	0.178	0.171	0.180	0.178	0.158
a_6	E	0.198	0.194	0.188	0.195	0.169
a_7	L	0.191	0.186	0.174	0.188	0.160
	IS Attributes					
b_1	B	0.224	0.215	0.223	0.223	0.224
b_2	C	0.173	0.198	0.213	0.159	0.175
b_3	W	0.221	0.215	0.217	0.218	0.221
b_4	T	0.164	0.163	0.150	0.179	0.165
b_5	Q	0.219	0.208	0.197	0.220	0.215
d_1	1989	0.346	0.497	0.497	-	-
d_2	1990	0.361	0.503	0.503	0.543	0.522
d_3	1991	0.294	-	-	0.457	0.478

Note: The definitions of the variables are given in Section 2 and in Table 1.
For convenience we set: $a_1+...+a_7 = b_1+...+b_5 = d_1+d_2+d_3 = 1$.

is not consistent with the estimates, which differ widely over consecutive years. Thus, if time series data are available, model (2), which utilizes information over several years, is better suited to producing a statistically reliable estimation of the firm effects, *c*. Finally, R^2 for the 20 firms for which we have data for 1989-1991 (see the column for 1989-1991 in Table 6) equals 0.49 (λ^2 = 51.44 and ZZ^2 = 105, see formula (10)). This indicates a fairly good estimate considering the simplicity of the model and the paucity of data.

5. Classification of firms

The firms in our sample are very heterogeneous (see Tables 1 and 2). The standard deviations are larger than the average values for all the original economic variables and for most of the economic variable normalized by the number of employees. The variability of the *IS* attributes, in absolute value as well as when normalized (divided) by the number of employees, is phenomenal. Thus, we decided to classify the firms into more homogeneous groups in order to usefully analyze the relations between the *IS* attributes and the economic variables across all firms. The hypothesis we wanted to test claimed that there are differences among the groups with respect to the correlation between economic variables and *IS* attributes within each group.

Table 7: Estimation Results for *c* (Firm Effect)

Firm	Four-Way Matrices			Three-Way Matrices		
	1989-91	1989-90	1990-91	1989	1990	1991
1. Abbott Laboratories	9.11	9.10	10.30	7.16	11.01	9.77
2. Ameritech Corp.	3.65	3.57	3.80	3.40	3.67	4.06
3. AMR Corp.	3.21	4.05	4.49	3.12	5.07	3.95
4. Banc One Corp.	5.51	5.10	5.30	5.67	4.39	6.78
5. Bell Atlantic Corp.	3.44	3.51	3.33	3.45	3.52	2.65
6. Dow Chemical Co.	8.43	9.36	7.63	9.41	8.99	6.19
7. Federal Express Corp.	4.22	4.93	4.04	4.79	5.17	2.67
8. Gillette Co.	5.14	4.92	5.72	4.01	5.67	5.79
9. Grumman Corp.	2.48	2.45	2.79	1.81	3.00	2.57
10. GTE Corp.	5.35	4.97	5.50	5.01	4.85	6.53
11. Inland Steel Industries Inc.	9.75	11.44	6.45	16.87	7.48	4.21
12. Martin Marietta Corp.	3.71	3.41	3.85	3.44	3.37	4.55
13. McDonnell Douglas Corp.	3.05	2.81	3.43	2.25	3.28	3.61
14. MCI Communications Co.	2.49	2.56	2.40	2.64	2.39	2.61
15. Merck & Co.	8.06	7.35	8.52	7.13	7.25	10.64
16. Northeast Utilities	6.70	6.45	6.68	6.77	6.03	7.34
17. Northrop Corp.	3.92	2.22	5.15	1.24	3.15	6.57
18. Sears, Roebuck & Co.	6.39	6.62	6.31	6.38	6.77	5.70
19. The Boeing Co.	3.17	3.56	2.94	3.92	3.31	2.52
20. The Dun & Bradstreet Co.	1.52	1.61	1.47	1.53	1.64	1.29

Note: The sum of the weights in each column in the table is normalized to 100.

There are several ways to classify the 20 firms according to the estimates of the *firm effect*, *c*. The following discussion uses the estimates of *c* for the entire data set, 1989-1991 (presented in column 1 of Table 7). Discriminant analysis, as well as simple observation, yields the three groups of firms listed in Table 8.

Note that all the aerospace and defence firms, as well as the firms that belong to the transportation sector, are in group α while all the industrial firms in our sample are in group γ. This may be just an artifact of the very small sample in this paper. However, there may be something specific in industries which promotes or detracts from the effect of *IS* on productivity. For example, during our sample period all the firms in the aerospace, defence and transportation sectors were engaged in fierce competition and, in certain instances, in attempts to create competitive advantage (see Due, 1993, 1994, Roach, 1994) to attract customers of other organizations. This strategy assumes that there is a fixed (or even shrinking) market for the product and, due to the fierce competition in the product market, these firms are continually developing systems that cleverly differentiate their products from those produced by their competitors. These competitive advantage systems have a relatively short life span. The end result may be reduced productivity. While our sample is too small for a detailed analysis of the firms within each group, our classification suggests that the analysis of *IS* productivity may require differentiation between firm and industry effects.

Table 8: Classification of Firms

Group	Firm	Industry
α	Grumman Corp.	Aerospace and Defence
	Martin Marietta Corp.	Aerospace and Defence
	McDonnell Douglas Corp.	Aerospace and Defence
	Northrop Corp.	Aerospace and Defence
	The Boeing Co.	Aerospace and Defence
	Bell Atlantic Corp	Utilities
	MCI Communications Co.	Utilities
	AMR Corp.	Transportation
	Federal Express Corp.	Transportation
	The Dun & Bradstreet Co.	Consumer Products and Services
	Ameritech Corp.	Pharmaceutical & Food
β	GTE Corp.	Utilities
	Northeast Utilities	Utilities
	Banc One Corp.	Financial Services
	Gillette Co.	Consumer Products and Services
	Sears, Roebuck & Co.	Retailing
γ	Abbott Laboratories	Pharmaceutical & Food
	Merck & Co.	Pharmaceutical & Food
	Dow Chemical Co.	Petroleum & Chemicals
	Inland Steel Industries Inc.	Manufacturing

The ranges of the estimates of the *firm effect*, *c*, for the firms in groups α, β, and γ are approximately 3 ± 1, 6 ± 1 and 9 ± 1, respectively. Following are the exact estimates of the average, the minimal value, the maximal value and the standard deviation of the estimates of *c* for each group:

Group	Average	Minimum	Maximum	Standard Deviation
α	3.17	1.52	4.22	0.78
β	5.82	5.14	6.70	0.69
γ	8.84	8.06	9.75	0.75

Clearly, the estimates of *c* are complicated functions of all the *IS* attributes and economic variables that were used to construct them. The pairwise correlation of *c* with each of these attributes and variables separately is low. However, the firms in each of the three groups have similar values for some of the *IS* attributes and economic variables, whereas across groups, firms exhibit very different values for the same variables and attributes.

Table 9 presents, for the three groups of firms, the mean values for 1991 of the variables and attributes that we analyze here, and the corresponding mean values when all the variables and attributes are normalized by the number of employees (to control for firm size). The figures for 1989 and 1990 are very similar to those of 1991, so they are not presented here. Several results emerge from Table 9. Whereas group β consists of the largest firms (largest in terms of sales, employees, and assets), groups α and γ consists of firms similar in size. However, group γ exhibits the smallest number of employees, the highest profits, and certainly the highest profits per employee. At the same time, group γ uses the least *IS* attributes, whereas group α, which exhibits the lowest productivity (in terms of profits and sales per employee), also features the highest inefficiency in terms of its use of *IS* attributes and employees.

It seems that the firms in group γ are more efficient in their use of inputs than those in groups β and α. The firms in group β are larger than those in α (and γ); they are somewhat more efficient than those in group α (they exhibit higher profits per employee), but less efficient than those in group γ. Thus, we interpret c as an index of the firms' operating efficiency.

Finally, the efficiency index c classifies the firms in our sample into three relatively homogeneous groups. Table 10 presents the pairwise correlations between the economic variables and *IS* attributes for all the firms together (as in Table 3) and for the groups α, β and γ, separately. Although the number of firms in each group separately is rather small, the general conclusion is quite clear: the correlations between the two sets of variables are much higher within groups of firms than for all the firms together. This conclusion is very pronounced for profits in group β (and to some extent in group γ as well), and for sales, for equity, and for assets in all three groups. Thus, we conclude that strong correlations exist between *IS* attributes and economic variables when the firms are grouped according to the "efficiency" index c, but not necessarily when they are grouped according to size or to industrial classification (on this issue see also Ahituv and Giladi, 1993, and Ahituv, Lipovestky and Tishler, 1996).

6. Summary

This paper presents a methodology for analyzing the relations among the economic variables and *IS* attributes of firms. The analysis is carried out using a multivariate statistical model in which data are represented by a four-way matrix. The use of the four-way matrix, formula (2), proves to be more successful than estimating the parameters for each year separately. The estimation results are robust in the initial conditions that were used, and convergence was achieved without difficulty.

One of the goals of this paper is to identify the marginal effect of the *IS* attributes on various economic variables of the firms. Formula (2), among others, uses the relations among all the economic variables in addition to all the *IS* variables. It provides a meaningful and reasonable estimate of the marginal effect of the *IS* attributes on the economic variables (given by the vectors a and b).

The multivariate analyses for the entire sample of firms suggest the following conclusions. (1) The economic variables sales and equity are those most affected by the *IS* attributes, whereas profits and change in profits - which are or should be the main goals of the firm - are least affected by the *IS*. This finding is in agreement with the results of Hitt and Brynjofsson (1994) who found that *IS* attributes support the increase in productivity (i.e., less "inputs" for more "outputs"), but, at the same time, they have little impact on profitability. (2) Of all the *IS* attributes that we considered here, the value of the firm's main processor and the amount spent on training employees in *IS* are best related to the economic variables that we used in this study. These two conclusions are also supported by the estimates of the pairwise correlations.

The multivariate model used in this paper classifies the sample into three relatively homogeneous groups. The overall, as well as the pairwise, correlations between the *IS* attributes and the economic variables are very high within each group, disproving the "productivity paradox". Grouping according to the methodology used in this study, by the efficiency index c, considered the economic variables and *IS* attributes, and can be used to classify firms according to their efficient use of inputs, in particular of *IS*. Group α, for example, is not only not "productive" in terms of sales per employee and profits per employee, but also exhibits high resources per employee.

Table 9: Mean Values of Firms' Economic Variables and *IS* Attributes (Absolute Value, and Value per Employee) Firms are Grouped According to c; Data are for the Year 1991

Variable		Group		
		α	β	γ
Economic Variables	Sales (S)	10363	16973	9477
	Profits (P)	522	689	1028
	Assets (A)	10951	34126	10120
	Equity (E0)	3676	5644	4212
	Employees (E)	72	134	41
IS Attributes	IS Budget (B)	619	483	202
	Main Processor (C)	307	175	72
	Wages in IS (W)	239	189	88
	Training in IS (T)	17	21	13
	Number of PCs (Q)	53	97	17

Variable per 1000 Employees		α	β	γ
Economic Variables	Sales (S)	152.9	177.3	216.3
	Profits (P)	7.6	14.4	22.9
	Assets (A)	159.1	585.0	218.8
	Equity (E0)	52.7	101.7	95.1
IS Attributes	IS Budget (B)	9.1	6.8	4.7
	Main Processor (C)	4.0	4.0	1.7
	Wages in IS (W)	3.6	3.9	2.1
	Training in IS (T)	0.3	0.5	0.3
	Number of PCs (Q)	0.8	0.7	0.4

Note: The units of measurement are as given for values in Table 1.

Table 10: Pairwise Correlation of Firms' Economic Variables and *IS* Attributes (Firms are Grouped According to c; Data are for the Year 1991)

		Economic Variables					
Group	*IS* Attributes	*S/L*	*ΔS/L*	*P/L*	*ΔP/L*	*A/L*	*E/L*
All Firms	*B/L*	0.26	0.26	0.07	0.14	0.30	0.26
	C/L	0.69	0.35	0.32	0.16	0.33	0.66
	W/L	0.32	0.24	0.16	0.22	0.12	0.25
	T/L	0.65	0.24	0.29	0.10	0.37	0.51
	Q/L	0.09	0.24	-0.10	0.08	0.38	0.16
α	*B/L*	0.55	0.33	0.53	0.20	0.47	0.53
	C/L	0.79	0.46	0.42	0.02	0.70	0.69
	W/L	0.62	0.34	0.75	0.32	0.46	0.59
	T/L	0.73	0.43	0.50	0.12	0.61	0.62
	Q/L	0.55	0.43	0.33	0.07	0.66	0.62
β	*B/L*	0.52	0.76	0.82	0.87	0.93	0.78
	C/L	0.99	0.17	0.87	0.58	0.28	0.93
	W/L	0.83	0.61	0.98	0.83	0.69	0.95
	T/L	0.65	0.81	0.91	0.81	0.81	0.85
	Q/L	0.22	0.20	0.32	0.67	0.84	0.46
γ	*B/L*	0.93	-0.08	0.18	-0.04	0.97	0.88
	C/L	0.62	0.55	0.82	0.62	0.62	0.83
	W/L	0.77	0.39	0.60	0.43	0.86	0.92
	T/L	0.98	-0.10	0.21	-0.04	0.99	0.92
	Q/L	0.99	-0.15	0.16	-0.09	0.99	0.91

The entire sample consists of very heterogeneous firms. However, a relatively homogeneous *IS* structure is observed within the three groups that emerge from the analysis. Within each of these groups, all *IS* attributes exhibit positive, and sometimes very high, correlations with profits, sales, equity, and assets. The positive association of these *IS* attributes with profits is particularly important. It indicates that all these *IS* attributes contribute positively to profits, the ultimate measure of success of the firm and its management.

Managers may be able to employ the model and efficiency index to identify the performance of their firm relative to the firms used to construct the index. With this information, they may develop a strategy for their use of *IS*, as well as for the use of other inputs in the production process.

Several conclusions about the appropriate use of *IS* seem to emerge from this paper's methodology and results (see, in particular, Tables 9 and 10). The correlations of the number of PCs per employee with profits per employee are relatively small in all three groups, and the correlations of the wages in *IS* per employee with profits per employee are very high in all three groups. These observations may suggest that firms should concentrate on selectively developing their *IS* staff rather than their *IS* hardware, in accordance with the specific characteristics of the firm.

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