Association for Information Systems
AIS Electronic Library (AISeL)

ICIS 1985 Proceedings

International Conference on Information Systems (ICIS)

1984

A Method for Assessing the Economic Impact of Information Systems Technology on Organizations

William G. Chismar
Carnegie-Mellon University

Charles H. Kriebel
Carnegie-Mellon University

A Method for Assessing the Economic Impact of Information Systems Technology on Organizations

William G. Chismar
and
Charles H. Kriebel

April 1985
Revised August 1985
GSIA Working Paper No. 40-84-85

Graduate School of Industrial Administration
Carnegie-Mellon University
Pittsburgh, PA 15213

ABSTRACT

Although the relative efficiency of information technology (IT) continues to improve at an exponential rate, the real investment in this technology throughout the economy is also expanding. Despite these two empirical facts, the ability of managements to assess the economic impact of IT on their organization's performance has not progressed very far in the past two decades. This paper presents a methodology for assessing the productivity of expenditures on information systems technology on the economic performance of business units (or profit centers), and demonstrates its use for several types of analysis within an organization.

A business unit is modeled as a production process that employs various input resources to produce commodities which yield economic outputs (such as profits, revenues, ROI, market shares, etc.). The approach employs microeconomic production frontiers to compare output performance of organizational units through the method of data envelopment analysis based on mathematical programming. With IT expenditures isolated as separate input factors, methods for analyzing business unit performance based on production efficiency are described. Application of these procedures to cross-sectional and to longitudinal investigations of empirical data are discussed, and numerical examples are included. While the approach is primarily descriptive at this stage, it provides guidance for more indepth normative study to determine preferred management practices.

Introduction

For some managers the information system resources in their organization are analogous to "public utilities," i.e., like the electric lights, they are taken for granted as long as they work. Still others argue that information technology (IT) today has become a strategic resource that is changing the structure of competition and determining which firms will survive (e.g., McFarlan, 1984). There are, of course, a range of other opinions between these extremes. Whatever one's persuasion, there are a few facts on which there is (almost) universal agreement: the relative efficiency of IT has and will continue to improve at an exponential rate. The real investment in this technology throughout the economy is enormous and increasing. Some organizations utilize and manage IT better than others. Prima facie, little progress has been realized in management's facility to measure the impact or contribution of IT to performance and the growing investment in systems.[1]

Information systems technology can produce different impacts at different levels of aggregation in the environment: for the individual, group, organization, industry, and economy or society. Obviously, there are different types of impacts which also vary depending on the "process" or phenomena of interest (e.g., see Bariff and Ginzberg, 1980). Our focus of interest is on economic impacts at the business unit/profit center and organization/business firm levels. In principle, the conventional procedure for evaluation of an IT investment decision involves a cost/benefit analysis to establish economic feasibility (e.g., one computes the NPV or DCF of benefits minus costs identified with the investment). Indeed, many organizations have institutionalized this process, èmploying elaborate documentation for the data which may include probability assessments. However, anyone who has participated in such an exercise soon realizes that it requires as much creativity and art as it does precision. Often the approach can bias the direction of investigation (e.g., towards the obvious cost savings or avoidance) and data reliability is a notorious limitation.

An axiom of information economics states that information has value for an individual only in relation to a stipulated decision context; "value" is not an inherent property of "information," but derives from the decision problem involved and the economic consequences of outcomes for the decision-maker. This construct of rationality presents operational difficulties when one seeks to extend it to an organizational setting, involving many decision makers over time.[2] In light of these problems several authors have proposed a behavioral measure as a surrogate for information value and "system effectiveness" (see Nolan and Seward, 1974 or Swanson, 1974). This candidate measure is "user satisfaction," which derives from an individual's "utility for information" and use of information system facilities (see Bailey and Pearson, 1983, Elam, et. al. 1984, Lucas, 1975).

Despite its seeming popularity, we find the logic defending "user satisfaction" as the appropriate measure of "system effectiveness" to be specious, and reliance on it as an (economic) output variable a potentially dangerous "leap of faith." It is curious to us that this approach ignores the extensive literature on research debunking the causality relationship between "job satisfaction" and "job performance" (e.g., see Campbell, et. al. 1970; Iaffaldano and Muchinsky 1985). Even under the most favorable scenario "user satisfaction" may be a *sufficient* condition for effectiveness or value in an economic context; nothing more.

Recently, Strassmann (1984) introduced a value-added productivity measurement concept for management as an approach to identifying the impact of information technology on business unit performance. In this approach "management" is defined as all components in an organization that are not "operations" and costs are categorized accordingly. The concept of "management value added is developed," and "management productivity" is defined as the ratio of management value added to management costs (or 1 plus gross profits before taxes divided by management costs).

In Strassmann (1985) the author argues that IT impacts and management productivity should only be measured at the business unit level or higher and then only as a group or team result, rather than as the summation of the "efficiencies" of individual managers. "Management productivity is an outcome rather than a cause" (p. 147). He argues further than productivity analysis of individual impacts of IT based on an industrial engineering view of the factory are inappropriate for the office and meaningless for an organizational perspective. We find these arguments compelling and they may help to explain the relative lack of progress in dealing with the basic issues. (See also Cron and Sobol, 1983 and van Nievett, 1984).

The method we propose in this paper is similar in concept to the position advocated by Strassman, although the details of executive are different. For clarification, it is not our intent here to present a methodological review or a comparison of various approaches to impact assessment. Rather we develop a theoretical basis for the evaluation process and describe a specific method within that framework (a later paper will present an empirical test of the procedure). Section two develops an approach for defining the economic performance. Section three addresses the problem of isolating the impact of the use of information systems on a business unit's performance. Procedures are described for accomplishing this task. Finally, section four illustrates some of these procedures through numerical examples.

Organizational Performance

The organizational literature is prolific with approaches toward measuring organizational performance, many of which are incompatible. At the heart of this problem is the existence of many varied conceptualizations of organizations with no concensus as to which is the most appropriate. Organizations, for example, have been characterized as goal-seeking entities, information processing units, purpose-based environments of stakeholder constituencies, and social contracts. Since the conceptualization of the organization dictates the types of performance measures, there also exists a wide variety of performance measures with no clear dominating measures. (See Cameron and Whetton, 1983, for a discussion of these issues.)

ECONOMIC PERFORMANCE AND EFFICIENCY

This research views an organization or strategic business unit as an economic artifact engaged in production processes. As such, the business unit utilizes input resources to produce its desired output products. The production process or technology that a business unit employs may vary across different business units, while units employing the same technology may differ in the levels of inputs utilized and the levels of outputs produced. This production view leads naturally to an efficiency measure of economic performance, which indicates how well (or efficiently) the inputs are being utilized to produce the outputs.

Before developing a measure of business unit efficiency, three issues must be addressed. First, input resources must be identified and measures of their utilization defined. Second, a similar analysis must be performed for the outputs of a business unit. Finally, the nature of the production process must be specified.

The resources used by a business unit can be categorized along several dimensions and to various levels of detail. Following a traditional microeconomic approach, we have factors of labor, capital, and frequently included, raw materials. These factors may again be divided into those relating to the production operations of the unit, and those relating to administration and management within the unit. Inputs can also be classified as being related to information systems or not. In general, the inputs of a business unit are its direct expenses and fairly easily identified.

The outputs of a strategic business unit are less easily identified. The obvious output of a business unit is the product or service produced. But, the aim of a strategic business unit is not simply to produce a product or a service. If the units being considered are limited to the private sector, the main goal of the unit is to be an ongoing, profit-making business. From this perspective the unit can be viewed as producing such things as revenues, market shares and customer relations. These types of outputs, while less easily identified and measured, better describe the actual contributions of a business unit.

Firms employing the same production process can operate at varying levels of efficiency. In comparing production across firms, microeconomics provides the concept of an efficient, or frontier, or a production function. This is a model which describes industry's "best practice" with current technology, i.e., the minimum combination of input factors to produce a specified level of output. This frontier production function provides a reference from which to judge the efficiency of the firms.

Consider, for simplicity, the case of firms employing two different inputs to produce a single output. Figure 1 displays a possible frontier production function for a given level of output production: the arc QP represents the frontier and is a unit output isoquant. Firms lying on this frontier, such as points A and B, are producing at maximum efficiency. Firms lying above the function in the plane, such as point C, are less efficient, because more of each input is being used to produce the same level of output. The efficiency of a unit can then be a measure of the distance that the unit is from the frontier: A measure of how productive the unit is relative to the maximum possible level of productivity.

To be precise, the unit at point C in figure one is using OC/OA times as much of each input as is the unit at point A. The inverse of this ratio, OA/OC, serves as a measure of relative efficiency. This measure of efficiency was originally formulated by Farrell as "technical efficiency" (Farrell, 1957) and has received considerable attention. This measure generalizes to the case of multiple outputs and inputs; although it cannot be displayed in a simple graph. The major task faced in using this measure is the determination of the efficient frontier.

FRONTIER ANALYSIS

In order to measure the efficiency of business units, a frontier production function for the units must be generated. If the exact nature of the production process is known, an engineering approach could be used to develop a precise technical description of the process (e.g. see Wibe, 1984). However, this is rarely the case; more commonly, the function is estimated from empirical data. For this estimation procedure, at least two basic approaches are available. The first consists of prespecifying a functional form and using the data to estimate the parameters of that function. The second entails generating an "envelope" which encloses all of the data points and serves as an estimate of the frontier production function.

The parametric approach begins by specifying the frontier as a parametric function, such as, Cobb-Douglas, CES or translog. (See Christensen, Jorgensen and Lau, 1973 for a description of the translog function.) Various econometric techniques are available to estimate the parameters of the frontier production function from the empirical data set. (See Broek, Forsund, Hjalmarsson and Meeusen, 1980.) The advantage of this approach is that it yields a detailed, mathematical formulation of the production process, allowing relationships among variables to be explicitly derived. However, the choice of a functional form can significantly influence the results of the frontier analysis (Forsund and Hjalmarsson, 1979) and the hypothesis of functional form cannot be directly tested: it must be taken on faith (Varian, 1984). Thus, in order to have any confidence in the choice of functional form, some detailed, prior knowledge of the production process is necessary.

In the second method, less prior knowledge about the production process is required and, therefore, fewer assumptions are necessary. A frontier surface or envelope is generated from the data set which exactly bounds that data set. Only a few, basic assumptions are made about the nature of the surface. Normal assumptions include that the surface be convex, have a negative slope everywhere, and be piecewise linear or, possibly, piecewise loglinear (Banker, Charnes, Cooper and Schinnar,

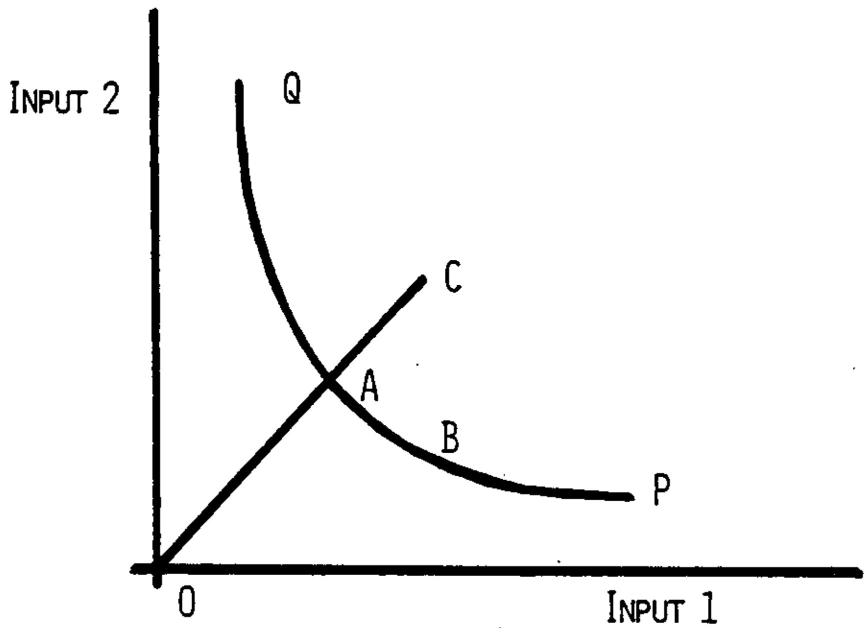

Figure 1

Illustrative Efficient Production Frontier

1981, and Banker, 1985). A major advantage of this approach, in addition to not requiring detailed prior knowledge of the production process, is its ability to handle multiple inputs and outputs with relative computational ease. A disadvantage is its sensitivity to the data set chosen. The addition or exclusion of a few data points could significantly alter the results. In addition, the method provides no direct means of handling measurement errors in the data.

It is clear that in modeling a strategic business unit as a production process there is little hope of obtaining prior, detailed knowledge of the process. The process of generating revenues and market positions from managerial and operational inputs is indeed quite complex. Assumptions made about the process must be carefully examined and should be kept to a minimum. Until a better understanding of the process is obtained there is little guidance for detailed model specifications. These facts argue for the use of the nonparametric approach for estimating frontier production functions in this research.[3]

Rhodes (1978) developed a linear programming procedure for carrying out the efficient frontier analysis, which he called 'data envelopment analysis''. The computation of unit efficiencies for n units can be achieved via the following n linear programming formulations (See also Charnes, Cooper and Rhodes,1981):

Max z_k
subject to:

$$-\sum_{j=1}^{n} y_{rj}\lambda_j + y_{rk}z_k \le 0 \quad ; \quad r = 1, \ldots, s$$

$$\sum_{j=1}^{n} x_{ij}\lambda_j \le x_{ik} \quad ; \quad i = 1, \ldots, m$$

$$\lambda_j \ge 0 \quad ; \quad j = 1, \ldots, n$$

$$k = 1, \ldots, n$$

where

$1/z_k$ is a measure of unit k's efficiency
x_{ij} is the amount of input i used by unit j
y_{rj} is the amount of output r produced by unit j
n is the number of units
m is the number of inputs
s is the number of outputs

Notice that there is one constraint for each output, one constraint for each input and a set of nonnegativity constraints. Solving the above linear programs will yield a set of n efficiency values for the n units. The efficiency of any particular unit will be equal to 1 if that unit is on the frontier surface and will be between 0 and 1 if the unit is inefficient.

The efficiency measure generated through the above analysis is a very useful measure of performance. Kriebel and Raviv (1980) employ a similar measure in evaluating the productivity of computer systems. Elam, et al. (1984) use this exact measure to evaluate the efficiency of data centers. In this research, with appropriate inputs and outputs defined, the measure serves as a measure of the relative performance of organizations.

Evaluating the Impact of Information Technology

With a measure of business unit performance defined, the task remains of isolating the relationship between expenditures on information systems technology by a unit or within an industry and changes in economic performance. Without a precise functional form of the production frontier, mathematical analyses that explicitly derive the IT contribution cannot be performed. However, other, albeit less quantitative, types of analysis are possible. This section proposes several categories of analysis for investigating IT impacts. The first category provides a means of identifying units or firms which have realized IT impacts on performance. The second category of analyses deals with specific IT impacts, such as, substitution of IT for other input factors. Finally, longitudinal types of analyses aimed at investigating the impacts of IT on a unit over time are discussed.

GENERAL IMPACT ANALYSIS

Farrell (1957) proposes an approach to investigating the impact of a single input factor on the efficiency of an industry consisting of a two state calculation. In the initial stage, unit efficiencies are calculated using all of the input factors except those relating to the single input in question. A second set of unit efficiencies is then generated using all of the factors. The result is two sets of efficiency values which maybe compared. Any differences which may exist can be attributed to the input factor of interest. From each set of inefficiencies, a distribution of efficiencies may be constructed. A comparison of these two distributions will provide insights into the effect of information system investments in unit performance. If there is little difference between the two distributions one could infer that the IS factors have little effect on overall unit performance. This type of analysis is analogous to studying step-wise regression.

Changes in performance levels may also be investigated at the level of individual units. Units can be grouped by the level of change in performance due to the inclusion of IS factors. Units with high levels of change in performance would seem to have realized a greater impact from information systems than did units with low levels of change. This procedure does not, unfortunately, provide the necessary framework for explaining any differences in levels of change; it does provide a means of identifying the units requiring closer study. Other factors, such as firm size, maturity of level of IS investment must be examined in an attempt to explain the differences.

Rerunning the data envelopment analysis with one less factor can alter the resulting reference sets. Thus, any given unit may have its performance determined with respect to a different set of units on the frontier in each of the stages. If this were the case then the comparison of the change in performance for that unit would have little meaning. Attention must be given in this analysis to changes in the reference sets across stages, i.e., changes in the facets making up the frontier and changes in the set of inefficient units encompassed by each facet. Given some change in unit performance ratings and little change in reference sets, the question arises of how to determine if a given level of change is meaningful or significant. No direct methods exist to do this and so the analysis must be subjective. Certainly, in the extreme cases, those cases with either large changes or very little change, the existence of significant or insignificant impacts may be safely inferred. In the other cases conclusions drawn from this type of analysis would be quite suspect.

SPECIFIC IMPACT ANALYSIS

The second category of methods of analysis attempt to identify specific impacts of investments in information systems. Within a microeconomic analysis a production function is used to determine technical rates of substitution between input factors; the rate at any given point on the function is equal to the ratio of the partial derivatives of the function with respect to the factors at that point. This exact analysis does not carry over to the linear programming approach since a functional form of the frontier is not generated. It is possible, however, to determine the slope of the frontier in any dimension. Since the facets comprising the frontier are linear, the slope will be constant on a facet. The slope represents the technical rate of substitution between the two factors in the chosen dimension and is equal to the ratio of the dual variables of the constraints for the two factors of interest (Rhodes, 1978).

The technical rate of substitution is useful in identifying certain types of impacts. Consider, for example, the possible impacts of investment in information systems for management. Two effects may be of interest: 1) The investment in IS may lead to a reduction in the level of other management input factors employed, while not affecting the level of output. This is a substitution of information systems resources for other resources. 2) The IS factors may lead to an increase in output without a corresponding increase in the use of other factors. These two effects both lead to an increase in performance and are not mutually exclusive.

Figure 2 shows a possible frontier analysis for units with a single output and two inputs, x_1 and x_2. The inputs could be expenditures on information systems for management and other management expenditures. Assume we are interested in isolating the effects of expenditures in x_1. The space may be divided into cones defined by the frontier facets, for example, regions I, II, and III in Figure 2. (the facets are defined by the efficient points at their corners.) Units in region I are employing a strategy of low levels of x_1 while those in region II, the opposite strategy. Any unit not operating efficiently has failed to realize a reduction in its level of x_2, has failed to realize an increase in its output, or is spending too much on x_1. Though the analysis connnot identify which of these possibilities is indeed the case, it provides beneficial guidance. The question remains as to why these differences in units exist. It may be that some attributes of the units, such as size or experience with IS technology, may help identify the groupings of the units. Though no causal relationships may be attributed, this type of analysis could provide some constructive insights into the issues.

LONGITUDINAL STUDY OF TIME-SERIES

Time series analysis, aimed at studying shifts of particular units in Figure 2, is also possible. Consider the unit at point B. This unit does not apear to be gaining any performance benefits from its large investments in x_1. It is possible that it may take some time for the impacts to be realized due to factors such as learning or adoption effects. If this were the case, time series data should reveal distinct shifts in the unit's position. For example, if the unit at B began, at some point in time, substituting input x_1 for x_2 its position should move toward the x_1 axis, e.g., to point C. If, however, no substitution was employed but output was being increased, the unit's position should move toward the origin, e.g., to point D. Combinations of these moves are also possible. The other possibility is that the unit is not realizing either of the benefits of investment in x_1. This would be evident if the position of the unit is not changing significantly over time, and the unit's investment of x_1 would certainly be questionable.

Time series analysis can also be useful in studying impacts on industries over time. By tracking changes in the frontier for a particular industry certain inpacts from investments in information systems technology may become evident. For example, changes in the rates of substitution between information systems and other input factors are measurable as changes in the slopes of the frontiers. Another example of an effect measurable over time, is the adoption of a technology by an industry. As the technology was being adopted successfully, there should be a shift of units toward the frontier; i.e., an increase in the performance of units as they learn to successfully use the new technology. Conversely, if the technology was not being used successfully, a shift in units away from the frontier would be observed.

The preceding discussion should provide some perspective on the variety of analysis that can be performed within the proposed framework, depending on the questions of interest. We now provide a numerical example to illustrate this versatility within a specific context.

Numerical Illustration

The example in this section illustrates some of the methods described in the previous section. The data set represents 19 firms within a single industry. The data relating to unit sales and overall expenditures were obtained from the Compustat database, while the data relating to information systems expenditures were generated based on industry statistics compiled by a management consulting firm. The analysis and results based on this data are intended for illustrative purposes only.

The complete data set is shown in Table 1. Two output mesures were selected, total sales and return on investment (ROI), along with five input varibles, nonproduction labor and capital, production labor and capital, and MIS expenditures. The results of the frontier analysis (as seen in Table 2a) show that nine of the nineteen firms are on the frontier, as indicated by a performance rating of one, with the remaining ten firms having performances ratings from .867 to .997. There is no clear relationship between the level of IS expenditures, measured as a percentage of total expenditures, and performance. The range on IS expenditures is .980 to 2.1, with a mean of 1.20, for the efficient units. For the inefficient units the range is 1.00 to 2.2 with a mean of 1.6. Note, however, that unit 2, which is efficient with a relatively high level of IS expenditures, appears to be realizing productivity gains from its information systems. This unit is a candidate for more detailed study as a potential example of "good" information systems technology use.

Contrasting unit 2 is unit 11; inefficient with an IS expenditure level of 2.2%—about the same level as unit 2. Though unit 11 has a performance rating of .969, it has a large slack in IS expenditures; implying it could reduce its IS expenditures by over 30% and not change its performnce rating. This indicates an ineffective use of its IS resources. A similar argument can be made about several other units.

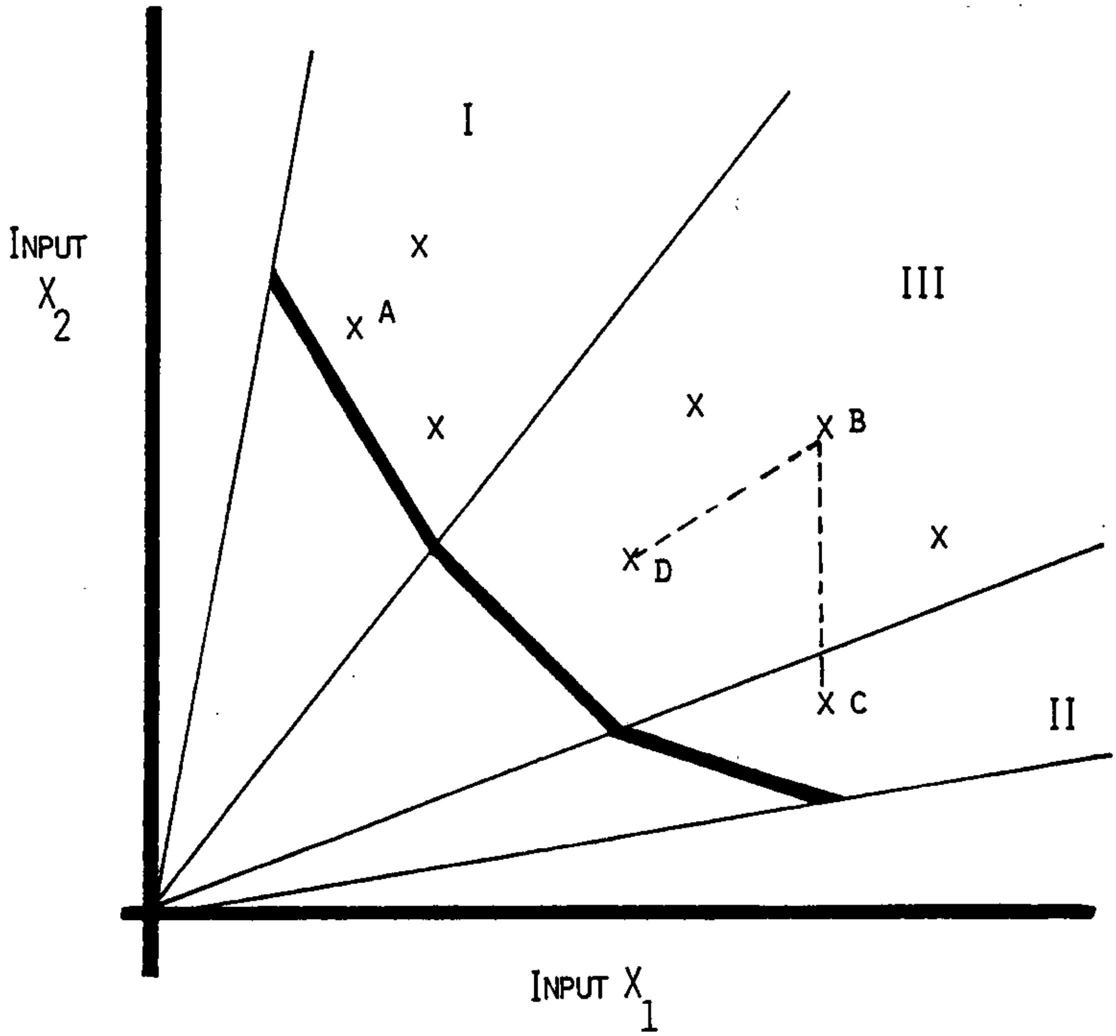

Figure 2

Frontier Analysis with Piecewise Linear Facets

Table 2b shows the resulting reference facts and their associated, inefficient units. This segmentation identifies the units to which a given unit is being judged inefficient. Thus, for example, units 3, 11, 12, and 16 are each inefficient relative to units 1, 2, 7, 9, and 10, which define facet A. More detailed studies may now be conducted within a well specified set of units in order to identify the reasons for performance differences. Possible reasons include differences in types of systems developed and used, differences in management practices, and differences in implementation procedures.

In order to determine specific impacts, such as the potential rates of substitution between information systems technology and other inputs factors, the substitutability and independence of the input factors must be specified. In this particular example, assume that 1) production and nonproduction inputs are independent, i.e., can not be substituted for each other. And 2) information systems expenditures are exclusively spent on administration, management,and other nonproduction applications. The specific impacts of interest are then the substitution of IS technology for nonproduction labor and capital.

Table 1

Data Set For Example

Unit	*Sales*	*ROI (%)*	*Nonprod Labor*	*Nonprod Capital*	*Production Labor*	*Production Capital*	*IS Expend*
1*	4856.500	0.259	423.923	1194.518	675.031	1370.518	63.135
2*	25.527	0.240	1.591	2.748	1.757	9.846	0.536
3	3917.001	0.191	627.568	1257.933	306.832	1012.368	39.170
4*	586.883	0.056	197.924	57.955	68.483	170.659	6.496
5*	374.914	0.189	66.151	32.485	87.954	126.569	5.624
6	36.976	0.043	11.116	4.495	5.581	13.021	0.555
7*	127.308	0.180	26.268	26.718	5.559	34.335	1.082
8	3033.701	0.189	570.667	634.934	329.306	676.094	28.820
9*	181.199	0.129	23.399	86.275	15.043	27.938	1.450
10*	3246.137	0.140	531.101	729.986	507.663	620.477	30.838
11	3750.001	0.159	393.542	1022.059	445.773	1016.527	82.500
12	1115.700	0.074	132.879	412.721	135.808	288.592	13.388
13	563.510	0.144	86.837	155.597	48.891	161.484	12.115
14	475.289	0.147	94.288	123.274	36.392	127.539	6.416
15	1808.500	0.116	305.782	618.718	218.718	349.382	33.457
16	946.00	0.114	134.868	302.732	116.262	211.238	18.447
17*	2835.390	0.216	634.839	533.394	265.149	610.265	24.384
18	1768.889	0.116	367.758	445.147	196.954	462.943	37.147
19*	870.200	0.203	202.136	229.299	70.331	156.543	11.313

* - Unit on Frontier   All figures except ROI in $MM

With the production input factor independent of the other factors, the frontier analysis can be rerun without them. Tables 3a and 3b show the results of the analysis using two outputs and three inputs: total sales, ROI, nonproduction labor, nonproduction capital and IS expenditures. The only change in the units comprising the frontier is unit 19, which is no longer on the frontier. The number of facets has decreased, as might be expected with decrease in the dimensionality of the problem. The composition of the reference sets also has not changed significantly. The technical rates of substitution of IS expenditures for nonproduction capital and for nonproduction labor indicate the amount of each factor that maybe replaced by one dollar of IS expenditures. Recall that the linerarity of the problem results in constant rates of substitution on a facet; so the rates for a facet apply to all of the units encompsses by that facet.

The most noticable result is the reversal in the magnitudes in the rates of substitution between facets B and C. This may indicate a significant difference in the types of information systems being employed in units in the two facets. Facet B is distinguished by its relatively large rate of substitution of IS for labor. Unit 11, encompassed by this facet, is spending proportionally more on IS, yet it is still spending about the same relative amount on labor as the other firms in the facet. This would tend to indicate that unit 11 is not realizing the full labor reduction benefits of its IS investment. Unit 3, on the other hand, has a low spending on IS and a higher relative spending on labor; indicating that it may be able to improve its performance by spending more on information systems technology. The rates of substitution can be used to do similar analysis with the other inefficient units.

Table 2a

Total Performance Ratings

Unit	*Performance Rating*	*IS Expend % of Sales*	*Reference Facet*	*Slack Inputs ($MM)*
1*	1.000	1.30	—	
2*	1.000	2.10	—	
3	0.955	1.00	A	PC (49.1)
4*	1.000	1.10	—	
5*	1.000	1.50	—	
6	0.867	1.50	B	IS (.005)
7*	1.000	0.85	—	
8	0.997	0.95	C	None
9*	1.000	0.80	—	
10*	1.000	0.95	—	
11	0.969	2.20	A	IS (32.05)
12	0.910	1.20	A	PC (5.75)
13	0.898	2.20	E	IS (2.69)
14	0.910	1.35	D	None
15	0.939	1.85	E	IS (14.44)
16	0.938	1.95	A	IS (7.55)
17*	1.000	0.85	—	
18	0.868	2.10	E	IS (9.35)
19	1.000	1.30	—	

* - Frontier Unit

PC - Production Capital
IS - Info. Sys. Expenditure

Table 2b

Reference Facets

Facet	*Corner Units of Facet*	*Encompassed Units*
A	(1, 2, 7, 9, 10)	3, 11, 12, 16
B	(2, 4, 5, 7, 17)	6
C	(2, 7, 9, 10, 17)	8
D	(2, 7, 9, 17, 19)	14
E	(2, 9, 10, 17, 19)	13, 15, 18

Summary and Conclusions

This paper has developed several methods of analysis for identifying the economic impact of information systems technology on business units and organizations. The approach is based on the microeconomic analysis of efficient production and employs a productivity measure of business unit performance. Numerical examples were presented to help illustrate applications of the methods, as well as their virtues and limitations at this stage of development.

The frontier analysis provides a mechanism for classifying business units (or firms) as either *efficient* or *inefficient* relative to all input factors and multiple economic outputs. To determine the specific impact or contribution of IT on performace, one requires isolating that factor within the analysis, *certeris paribus*. Employing a parametric approach, the item of interest here would be the

Table 3a

Performance Ratings Without Production Inputs

Unit	*Performance Rating*	*Reference Facet*	*Slack Inputs ($ MM)*
1*	1.000	—	
2*	1.000	—	
3	0.929	B	None
4*	1.000	—	
5*	1.000	—	
6	0.858	C	None
7*	1.000	—	
8	0.987	D	None
9*	1.000	—	
10*	1.000	—	
11	0.736	B	Capital (51.75)
12	0.905	B	None
13	0.681	A	None
14	0.794	A	None
15	0.667	A	None
16	0.691	A	None
17*	1.000	—	
18	0.656	A	None
19	0.765	D	

* - Frontier Unit

Table 3b

Reference Facets and Rates of Substitution

Facet	*Corner Units of Facet*	*Encompassed Units*	*Substitution IS/Capital*	*Substitution IS/Labor*
A	(1, 2, 5, 10)	13, 14, 15, 16, 18	17.14	22.18
B	(1, 2, 9, 10)	3, 11, 12	20.10	70.67
C	(2, 4, 5, 7)	6	52.30	19.16
D	(5, 7, 10, 17)	8, 19	24.16	23.07

numerical coefficient(s) for IT in the specified production function. In the non-parametric case, such as DEA, the impact can be inferred by employing the analysis with and without the inclusion of IT as an input factor and noting changes (or shifts) in the respective frontiers. Additionally, one might approximate technical rates of substitution between IT and other input factors as the slope of the tangent to the envelope curve which encompasses those units on the production frontier. Obviously, discreteness in the non-parametric case (especialy with limited data points) reduces precision in the analysis and one should be cautious in drawing inferences.

In the numerical illustration (see Tables 1 and 2) at the global level we find efficient and inefficient units with varying levels of IT expenditures, some more and some less in each category.[4] The analysis highlights unproductive expenditures on IT (as "slack") by units in the interior relative to their reference peer group on the frontier. However, this observation can be misleading with cross-sectional data due to time lags between investment and returns to performance. The solution to this dilemma is time series data which would permit one to track unit behavior over time relative to frontier performance, IT expenditures and other input factor costs (all in real terms).

The major problem facing researchers studying the economic impact of information systems technology is the unavailability of data. Data identifying expenditures on information systems technology are being collected in very few firms and time series data are essentially nonexistent. Standard accounting and financial data are inadequate for this research. If the impacts of investments in information systems technology are to be identified and studied, firms must begin collecting reliable data about these investments.

NOTES

[1] An extensive literature in support of these observations exists. See for example Benjamin (1982), Jonscher (1983), Stabell and Forsund (1982), and Strassmann (1985).

[2] But see Marschak and Radner (1972), McGuire and Radner (1972) and Kriebel and Moore (1980).

[3]Stabell (1982) chose to employ the first method in his research because of the sensitivity of the envelope approach to the data set. He does state that his work relies on being able to validate the choice of a parametric production function—a Cobb-Douglas function in his case. He does not, however, provide a method for validating his choice.

[4] It is worthwhile to note that this situation (i.e., the bimodality of IT expenditures and performance data) is consistent with the findings reported in Cron and Sobol (1983) and Strassmann (1985). That is, large investments in IT is not a cure for poor management, but it may enhance the performance of good management. See also Stabell and Forsund (1982).

REFERENCES

Bailey, J.E. and S.W. Pearson, "Development of a Tool for Measuring and Analyzing Computer User Satisfaction," *Management Science*, 29, 5 (May 1983), 530-545.

Banker, R.D.,"Productivity Measurement and Management Control," Forthcoming in *The Management of Productivity and Technology in Manufacturing*, Paul Kleindorfer (Ed.), Plenum Publishing Company, 1985.

——, A. Charnes, W.W. Cooper, and A.P. Schinnar, "A Bi-extremal Principle for Frontier Estimation and Efficiency Evaluations," *Management Science*, Vol. 27, No. 12, December 1981, pp. 1370-1382.

Bariff, M.L. and Ginzberg, M.J., "MIS and the Behavioral Sciences: Research Patterns and Prescriptions," 49-58 in McLean (1980).

Benjamin, R.I., "Information Technology in the 1990s: A Long Range Planning Scenario," *MIS Quarterly*, Vol. 2, No. 6, June 1982, pp. 11-32.

Broek, J. van den, F.R. Forsund, L. Hjalmarsson, and W. Meeusen, "On the Estimation of Deterministic and Stochastic Frontier Production Functions: A Comparison," *Journal of Econometrics, 13, 1980, pp.117-138.*

Cameron, K.S. and D.A. Whetten (Eds.), Organizational Effectiveness: A Comparison of Multiple Models, New York, N.Y., Academic Press, 1983.

Campbell, J.P., M.D. Dunnette, E.E. Lawler, and K.E. Weick, *Managerial Behavior, Performance and Effectiveness* (McGraw-Hill, Book Co., N.Y., 1970).

Canning, R.A. (Ed.), "How The Management Job is Changing," *EDP Analyzer*, Vl. 22, No. 6, June 1984.

Charnes, A., W.W. Cooper, and E. Rhodes, "Evaluating Program and Managerial Efficiency: An Application of Data Envelopment Analysis to Program Follow Through," *Management Science*, Vol. 27, No. 6, June 1981, pp. 668-697.

Christensen, L.R., D.W. Jorgensen and L.J. Lau, "Transcental Logarithmic Production Frontiers," *Review of Economic Studies*, Vol. LV, 1(1973), 28-45.

Cron, W.L., and M.G. Sobol, "The Relationship Between Computerization and Performance: A Strategy for Maximizing the Economic Benefits of Computerizaiton," *Information and Management 6(1983), 171-181.*

Elam, J.J., J.C. Henderson, and J. Thomas, "Evaluating the Efficiency of the Information Systems Function," unpublished working paper, University of Texas at Austin (1984).

Farrell, M.J., "The Measurement of Productive Efficiency," Journal of the Royal Statistical Society, Vol. 120, Series A, Pt. III, 1957, pp. 253-290.

Forsund, F.R. and L. Hjalmarsson, "Frontier Production Functions and Technical Progress: A Study of General Milk Processing in Swedish Dairy Plants," *Econometrica*, Vol. 47, No. 4, July, 1979.

Iaffaldano, M.T. and P.M. Muchinsky, "Job Satisfaction and Job Performance: A Meta-Analysis," *Psychological Bulletin*, Vol. 94. (2) March 1985, pp. 251-273.

Jonscher, C., "Information Resources and Economic Productivity," *Information Economics and Policy* 1(1983), 13-35.

Kriebel, C.H., and J.H. Moore, "Economics and Management Information Systems," 19-31 in McLean (1980).

Kriebel, C.H. and A Raviv, "An Economics Approach to Modeling the Productivity of Computer Systems," *Management Science*, Vol. 26, No. 3 (March 1980), pp. 297-311.

Lucas, H.C., Jr. *Why Information Systems Fail* (Columbia University Press, New York, 1975).

Marschak, J. and R. Radner, *Economic Theory of Teams* (Cowles Foundation, Yale University Press, New Haven, 1972).

McFarlan, F.W., "Information Technology Changes the Way You Compete," *Harvard Business Review* 62,3 (May-June 1984), 98-103.

McGuire, C.B. and R. Radner (ed.), *Decision and Organization* (North Holland Publishing, Amsterdam, 1972).

McLean, E.R. (ed.), *Proceedings of the First International Conference on Information Systems* (Society for Management Information Systems, Chicago, IL, 1980).

Nolan, R.L. and H.H. Seward, "Measuring User Satisfaction to Evaluate Information Systems," 253-276, in R.L. Nolan (Ed.), *Managing the Data Resource Function* (L.A. West Publishing Co., 1974).

Rhodes, E., "Data Envelopment Analysis and Related Approaches for Measuring the Efficiency of Decision Making Units with an Application to Program Follow Through in U.S. Public School Education," unpublished dissertation, Carnegie-Mellon University, School of Urban and Public Affairs, Pittsburgh, 1978.

Stabell, C.B., "Office Productivity: A Microeconomic Framework for Empirical Research," *Office: Technology and People*, Vol;. 1, No. 1 (1982), pp. 91-106.

——and F. Forsund, "Productivity Effects of Computers in Administration: An Exploratory Empirical Investigaiton," Unpublished working paper, Norwegian School of Economics and Business Administration, May 1982.

Strassmann, P.A., *Information Payoff: The Transformation of Work in the Electronic Age*, New York N.Y., The Free Press, 1985.

——, "Value-Added Productivity Measurement: Concepts and Results," *EDP Analyzer*, Vol. 22, No. 6, June 1984, pp. 13-14.

Swanson, E.B., "Management Information Systems: Application and Involvement," *Management Science 21*, 2 (October 1974), 178-188.

van Nievett, A.C. Augustus, "Management Productivity and Information Technology," *Information strategy: The Executive's Journal*, 1, 1(Fall 1984), 9-15.

Varian, H., "The Nonparametric Approach to Production Analysis," *Econometrica*, 52(1984), 579-597.

Wibe, S., "Engineering Production Functions: A Survey," *Economica*, 51(1984), 401-412.