A review and analysis of the state-of-the-art research on productivity measurement

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Abstract
Productivity measurement is a required management tool in evaluating and monitoring the performance of a business operation. The purpose of this paper is to provide an analysis of the state-of-the-art research on productivity measurement. The paper comprises two major sections. First, to develop some consensus about the techniques that can be employed, the theory of productivity measurement is examined and evaluated from several perspectives. Second, based on the availability of diverse techniques for measuring productivity, we analyze innovative case and field studies that demonstrate the techniques an organization can employ to measure performance adequately.

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Introduction

It is argued that productivity is one of the basic variables governing economic production activities, perhaps the most important one (Alby, 1994). At the same time, productivity has too often been relegated to second rank, and neglected or ignored by those who influence production processes. Although, in recent years, the pressures of an increasingly global economy have compelled firms to focus on strategies for productivity improvements, issues related to the measurement of productivity have still not received adequate attention. This state of affairs is complicated by two factors. First, as our survey will establish, improvements in the methodology of productivity measurement have been diverse and piece-meal at best. Second, at the operational level most firms do not seem to implement adequate productivity measurement procedures (Belcher and John, 1984; Alby, 1994; Sudit, 1995). A common tendency is to measure performance by whatever data are readily available, without adequate cost-benefit calculations about establishing new data gathering priorities to improve the tracking of performance.

The purpose of this paper is twofold. First, we survey recent developments in the literature related to issues of productivity measurement to develop some consensus about the techniques that can be employed. This task is made difficult by the fact that productivity measurement is a complex issue that incorporates at least three different disciplines: economics, management and accounting. Researchers from each discipline while developing new insights about measuring productivity have devoted less attention to how these developments can be integrated to develop a consensus on the issue. Second, based on the availability of diverse techniques for measuring productivity, we analyze innovative case studies that demonstrate the techniques a typical manufacturing or service firm can employ to measure performance adequately.

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Approaches to productivity measurement

Within a broad context, there are three diverse techniques of productivity Measurement:

1. *Index measurement*: Although, the most prevalent concept is that of Total Factor Productivity, other types of indices can provide valuable insights, particularly those exploiting the data that is available in a standard accounting framework.
2. *Linear programming*: This approach constructs a production frontier and evaluates each input's contribution to the productive process based on past performance data. The approach does not require price data on inputs and products, quantities of inputs can be directly utilized. The most prevalent programming technique is Data Envelopment Analysis (DEA).
3. *Econometric models*: Although, initially the requirement of a specific functional form made the estimation of econometric models restrictive, the development of flexible functional forms and more efficient algorithms have made this approach quite useful, particularly if there is a wide array of inputs. Two disadvantages are that the approach requires price data and at least 30 or 40 degrees of freedom.

Index measurement of productivity

By far the most common procedure for assessing productivity changes is by developing some form of indices. Hawaleshka and Mohamed (1987) provide a pertinent discussion of the advantages and disadvantages

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of five common ratios employed to measure productivity: Single Factor Productivity, Multifactor Productivity, Total Productivity, Managerial Control Ratio and Productivity Costing. The model proposed by Craig and Harris (1973) for Total Factor Productivity is the representative genre in this group. Basically, the model proposes measuring productivity as a ratio of output to different inputs. In the original article, Craig and Harris go through an intensive discussion of what type of inputs should be included. Since every firm may have a different configuration of potential inputs, we need not discuss this aspect intensively.

Two controversies which generally arise in the Craig and Harris type of index are the issue of base periods and price adjustments. Rao (1993) shows that the design of an optimal base period is important in measuring productivity. If there are errors in a typical threshold base period, the errors will distort the productivity measurement considerably.

The issue of price adjustment can be discussed within the context of two common models based on the index approach: American Productivity Center's total factor model (APC) and Ethyl Corporation's (PPP) model in which Profitability = Productivity + Price Recovery. A detailed description of the APC model can be found in Belcher and John (1984) and the PPP model is fully described in Miller (1984). The PPP and the APC models have different ways of deflating price changes. Basically, the PPP approach developed for finance managers utilizes a cumulative deflation method and maintains dollar values throughout its analysis. On the other hand, the APC model uses period to period deflation to arrive at unit-less ratios. Consequently, PPP focuses on productivity changes between the current period and all previous periods, whereas the APC approach relates current period productivity to the base period only. Miller and Rao (1989) while comparing the two approaches have shown that differences in the method of price deflation can significantly affect the proper choice between the APC or the PPP model. Specifically, the PPP approach provides a more suitable tool for examining productivity changes over a trend of at least three or more periods. On the other hand, since the APC approach utilizes only the base period prices, its price weights are independent and separable and more suitable for a two period comparison.

Extensions of the index measurement approach to productivity spill over to finance and accounting frameworks. Two examples will demonstrate these useful additions. Miller (1987) shows how the total factor productivity measurement procedures can be amended by utilizing a target rate of investment (ROI) instead of gross profit margins (GPM) to measure profitability and productivity gains. This approach provides a useful foundation for developing better capital management strategies. Specifically, the net contribution of capital from different elements can be decomposed to develop priorities for better capital utilization.

Banker *et al.* (1989a) extend the concept of productivity measurement by utilizing a standard management accounting framework. Given the availability of a technological specification (the combination of different inputs used to produce output for a given technology) they decompose the intraperiod variance between budgeted profits and actual profits by the following formulation:

Profit variance = sales activity variance + productivity variance + price recovery variance

The first term captures changes in profits due to sales variations. The second term captures improvements in productivity whereby the production threshold volume for the year is produced by a lower combination of inputs. The last term measures changes in profits because of price fluctuations.

Subsequently, they normalize these three sources of profit variance by appropriate denominators so that percentage change variances between two periods can be computed. In this way, percentage change in profits over two periods can be decomposed into percentage changes due to sales activity, price recovery and productivity.

The major difference in the measurement procedures proposed by Banker *et al.* (1989a) is that it employs a technological specification (ratio of given inputs to produce output). In sharp contrast, the APC system employs actual quantities and prices of both inputs and outputs to compute productivity and price recovery ratios. Since the APC system utilizes values (price times quantities) to aggregate across multiple outputs and inputs, it is possible for the APC system to show changes in productivity due to shift in the output mix rather than change in the efficiency of the productive process. The fact that the technique utilizes information available in the standard accounting framework is an advantage. However, knowledge of the technological specification is required. The APC procedure by not requiring knowledge about the input output conversion ratios can be employed more easily.

Programming measures of productivity

The programming procedure for measuring productivity changes has two antecedent advantages: it does not require price data and specific functional form. The most common programming procedure for productivity changes is the data envelopment analysis (DEA). A technical discussion of DEA can be found in Banker *et al.* (1989b). DEA is a flexible, non-parametric estimation procedure which identifies the contribution of a set of inputs for achieving the maximum quantities of a given set of outputs. The mathematical programming procedure estimates a multi-surface production frontier based on different combination of input/output ratios. The advantages of DEA are as follows:

1 DEA permits an extended set of inputs and outputs. Unlike the APC formulation which focuses on output maximization alone, DEA can be utilized to maximize several output criteria at the same time. For instance, the traditional output variable and export promotion can be jointly maximized. The procedure is suitable for utilizing non-traditional inputs represented by qualitative data, since price valuation is not required.
2 Since the procedure is non-parametric, it does not require a specific functional form. This can be viewed as an advantage since an initial choice of a wrong functional form can lead to serious specification errors. Other restrictive conditions, such as causality and error term properties are not required in DEA.
3 Simulations and theoretical considerations indicate that the estimation procedure is statistically robust. For instance, Banker *et al.* (1989b) show that compared to the flexible trans-log estimation procedure generally employed by economists, DEA is able to map the potential output hyper-plane more effectively and is relatively robust.
4 DEA employs separate optimization routines for each input variable, consequently, it can trace specific inputs which are utilized less efficiently in the productive process.

The disadvantages of DEA are two-fold. First it requires a fairly large series of data so that the optimization can be estimated with a more general set of benchmarks. Second, being a non-stochastic procedure, tests of statistical significance are harder to develop.

Recently, stochastic considerations have been introduced by Chance Constrained Programming (CCP). Land *et al.* (1990) and Cooper *et al.* (1995) have shown the potential of CCP which treats input and output as random variables with a specified joint-probability distribution. This approach results in the construction of stochastic production frontiers in which some proportion of observations are allowed to exceed the frontier. The robustness properties and the specific advantages of the DEA approach still accrue, with the additional advantage of employing statistical tests of significance.

Econometric productivity models

Sudit (1995) provides a comprehensive discussion of different types of econometric models for measuring productivity changes. It is important to realize that econometric estimation methods require prior technological knowledge of the specification and knowledge of the technology process. On the other hand if prior knowledge of the functional form is not available, models with flexible functional forms can be utilized. However, one must recognize the basic tradeoff in that flexible functional forms require a larger sample size for estimation of more parameters.

A discussion of the most common econometric models will illustrate this tradeoff more clearly. As Sudit (1995) points out, one can allow for embodied technological change (technical change which affects output not only directly but also through the substitution of inputs) by the following specification:

$$Y = f({}_{Z}X,{}_{t}),$$

In this specification, a single output (*Y*) is a function of multi-inputs (*X*) and a technology index (*t*) which acts as an additional input variable. The technical change represented by the technology index (*t*) is often referred to as Hick's neutral technical change, which "shifts" the production function to higher output levels without altering the substitutability relations among the inputs. If we want to allow for "embodied" technical change, "*z*" is included as a vector of different efficiency factors for inputs to allow technical change through different combination of inputs. The above specification is difficult to estimate because it requires knowledge of the "*z*"s, which in turn may change the functional form. Typically, the specification is estimated as two samples of production data, each pertaining to a different technology and subject to different substitutability of inputs. When prior knowledge of technology is not readily available, a translog production function popularized by Christensen et al. (1973) is generally employed:

$$\ln Y = \gamma 0 + \sum \gamma_{ij} \ln X_j + \frac{1}{2} \sum \sum \gamma_{ij} \ln X_i \ln X_j$$

In this translog function, technical change can be inserted as an additional input ($X_n + 1 = t$). Translog forms are flexible in that they are second order approximations to any arbitrary twice differentiable logarithmic function. However, as stated earlier this flexibility requires a larger sample because of the large number of independent variables.

Typically, when we utilize sample data for the estimation of production functions, we cannot assume that all the past observations are technically efficient observation points, i.e. some are bound to be inside the production frontier. With a world characterized by an abundance of technological change, a firm is always learning to adjust to its constraints and maximize in a dynamic environment. It stands to reason that for some time the process of learning implies that it will not always operate on the production frontier. What this implies for the econometric process is that when we estimate the above equation based on historical sample data we do not obtain a production frontier, but rather an "average performance" production frontier. If we treat the estimated results as a production frontier, we will significantly underestimate production possibilities by regarding all observation points as being on the frontier.

This basic difficulty with production functions has made economists estimate frontier production functions (Aigner *et al.*, 1977). In order to distinguish and capture inefficiencies, a one-sided error term which can only take non-positive values is introduced in the estimation process. A number of alternative density functions have been proposed for this constrained error term. Aigner (1977) assumes that the absolute values of the error term are distributed as a normal distribution, whereas Greene (1980) employs a Gamma distribution for the frontier error term. The estimation routine to estimate the frontier technical production functions, conditional maximum likelihood techniques are generally employed.

Complementarity of different measures

Although, the three procedures discussed in this article are based on philosophically divergent approaches, the differences in data requirement, initial assumptions, prior knowledge etc. implies that they should be utilized in a complementary manner. As Sudit (1995) points out, we could employ the DEA methodology to find the technically efficient production observation points and subsequently estimate a translog econometric function to obtain a production frontier. Clearly, when a large data series is available, the DEA and econometric procedures can provide valuable insights about the production capabilities compared to the indices approach to productivity measurement. The latter approach is suitable for measuring performance compared to a base period.

To put it in more functional terms, the different approaches provide answers to different questions. If the question is: "How did we perform compared to three years ago?", the answer is more readily available by computing productivity changes based on some variation of the indices approach. If we do not have price data, and the question is, "Which inputs are utilized inefficiently in our productive process?" then the answer can by obtained by DEA analysis. On the other hand if the question is, "To what degree is capital substitutable with labor, given our technological specification?", the answer is best obtained by an econometric production function. As we have shown, there is considerable flexibility within each framework based on different modifications provided by researchers to pick and choose the options which are best suited for a manufacturing firm.

In the next section, we review specific case studies to show how the literature on productivity measure measurement can be utilized by a typical manufacturing or service firm.

Empirical studies of productivity measurement

Table I summarizes the empirical studies (case and field studies) conducted in the area of productivity measurement. In this section, we discuss two specific case studies illustrating different productivity measurement procedures and which analyze productive measurement issues using an innovative approach under each of these methods.

Index approach

Prasad (1993) shows that besides looking at Labour Productivity Index by traditional control charts, the application of time series models can provide additional insights. He employs the generalized m-estimator (GM) procedure to model an Autoregressive AR (p) production process for the Cessna Aircraft Company to identify additive and innovative outliers. An additive outlier flags a one time

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Table I
Summary of the empirical research on productivity measurement

Author(s) (year)	Approach used	Industry/application setting	Findings
Fuller (1988)	Index measurement	Computer manufacturing	Shows how using a productivity loss index helps in enhancement of productivity and quality
Sengupta (1988)	Linear programming	Manufacturing	A robust minimax approach is used to measure productive efficiency
Conrad (1989)	Econometric models	Manufacturing	An extended framework was developed to reflect the efficiency aspect of productivity gaps in terms of cost disadvantages
Pritchard *et al.* (1989)	Index measurement	Manufacturing	A new approach to the measurement and enhancement of organizational productivity is described and evaluated
Omachonu *et al.* (1990)	Index measurement	Technical installation	A methodology for measuring the productivity of engineering and technical organizations is developed
Yousif and Dale (1990)	Index measurement	Hardware manufacturing	Total and partial productivities are similar when calculated using fixed and current prices
Pritchard and Roth (1991)	Econometric models	Manufacturing	Inclusion of non-linearities result in more valid productivity composites
Brown and Gobeli (1992)	Index measurement	Research centers – manufacturing	An R&D measurement system can be as complex or as streamlined as the managers wish
Mady (1992)	Index measurement	Manufacturing	An integrated, easy-to-implement model for measuring productivity in real terms is presented
Ray and Sahu (1992)	Index measurement	Manufacturing	Suggests a combination of production factors with which management would be able to increase the productivity of the products
Radovilsky and Gotcher (1992)	Econometric models	Electronic equipment	The main loss factors in terms of productivity improvement are ineffective technology design, overstocked inventory, poor product quality, and wrong work standards
Prasad (1993)	Index measurement	Aircraft industry	Uses the M-type interactive procedure (a time series method) to monitor the labor productivity index over time
Bogetoft (1994)	Linear programming	Manufacturing	An illustration of how to design optimal incentive schemes based on DEA frontiers is provided
Elmuti and Kathawala (1994)	Index measurement	Production planning and control	The traditional productivity index measures show a positive impact of participation in the Deming quality improvement program on employee productivity
Saha (1994)	Index measurement	Chemical	Describes the application of TOPROD, a software for total productivity measurement in a chemical processing plant
Wilson (1994)	Linear programming	Manufacturing	Presents an improved goal-oriented method for productivity measuring and monitoring of performance of manufacturing firms
Jablonski (1995)	Index measurement	Broadwoven fabrics	Technological change was the most important factor underlying multi-factor productivity growth in the period
Kleiner *et al.* (1995)	Economic models	Manufacturing	Production-related residual grievances was correlated to increased managerial monitoring (that had a positive impact on productivity)

(continued)

Table I

Author(s) (year)	Approach used	Industry/application setting	Findings
Nohria and Gulati (1995)	Econometric models	Production planning and control	An inverse U-shaped relationship exists between organizational slack and innovation in multinational firms
Sueyoshi (1995)	Linear programming	Telecommunications	A new DEA application to production analysis in different time periods is illustrated
Balvers and Bergstrand (1997)	Economic models	OECD countries and US	Offers insight into the robust cross-sectional relationship between relative per capita GDPs and relative national price levels
Birechee and Konzelmann (1997)	Economic models	Corn, processing, steel, paper and coal	Increasingly aggressive/adversarial labor relations characterize firms that have chosen to follow the low-wage path
Ford and Pittman (1997)	Economic models	Technical institute	Created a unique program and CI mode that has significantly increased productivity and profitability

change in productivity, whereas an innovative outlier tracks a continuous change in productivity. The predictive and analytical properties of the time series approach is able to identify and distinguish between one-time level shifts and continuing changes in productivity.

Jones *et al.* (1993) discuss a comprehensive work group performance and productivity measurement system designed for two departments of a small retail corporation. This system incorporates key dimensions of performance and integrated multiple measures into a composite index using a productivity measurement and evaluation system methodology. Subsequent to development, the measurement system was successfully used in one of the departments as a monthly feedback system. A significant improvement was found in a comparison department that did not receive feedback. In addition, a process methodology was used to assess the users' reactions to the measurement system. Qualitative analysis procedures indicated that the users' reactions were slightly positive, although many suggestions for improvement were offered.

Programming approach

Sueyoshi (1995) has extended the traditional DEA approach for comparing performances in different time periods. Initially, employing a data set of ten decision making units (DMUs) spanning two time periods (1985 and 1990) he shows the "Overall Time Efficiency" can be broken down into four efficiency concepts: overall efficiency, scale efficiency, price efficiency and time efficiency. In addition to the illustrative data set of ten DMUs, the study analyzes the four efficiency components for seven regional bell operating companies (RBOCs). The study indicates that regional bells have had problems with price efficiency (partly due to increased salaries and regulation) but have done well in terms of scale efficiency (plant sizes have been optimally utilized).

DEA has also been successfully used for assessing the productivity of complex organizations. For example, Ludwin and Guthrie (1989) used DEA for measuring the relative efficiencies of 36 elementary schools in Fort Wayne (Indiana) Community Schools district. The changes in inputs and outputs required to bring inefficient DMUs to a relative efficiency rating of one were identified and a guide for improving outputs that provided the basis for programme improvement were formulated. The authors concluded that DEA offered promise for productivity improvements in the public sector where multiple, non-priced outputs were the norm rather then the exception.

Econometric approach

Appelbaum and Berechman (1991) developed a market equilibrium model to calculate the rate of growth in productivity in Israel's bus transit sector. The economic variables used for developing the model and relationship included input prices, technical change, output scale, demand conditions, and government regulation. In this model supply (cost), demand, and regulatory conditions are explicitly taken into consideration. The results show that, while productivity (cost efficiency) did not change significantly in the sample period (1972-1981), average cost did increase in the latter part of the period. The effects of technical change, government regulation, and demand conditions were found to be insignificant.

Radovilsky and Gotcher (1992) present a new measurement system for analyzing productivity growth. This system is twophase. First, based upon a factor analysis of loss variables the common loss factors are determined. Next, these common factors are used as independent elements in a multiple regression model of productivity. The implementation of this two-phased model in an electronic equipment company showed that the main loss factors in terms of productivity improvement were ineffective technological design, overstocked inventory, poor job design, poor product quality, and wrong work standards.

Conclusion

Remaining competitive requires a company to operate in an efficient and orderly manner. Using the formula of outputs-inputs can sometimes be deceiving in determining overall performance. Performance measurements that reflect the operational strategy of the company should be developed and used.

The theoretical and empirical sections of this paper clearly point out that there is no one method for every company. However, in general, productivity measurement, as well as indexes and comparisons, can provide an objective source of information about long-term operating trends, draw attention to problems of performance, and inspire a useful exchange of ideas.

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