PN-AAV-298
45189

On Measuring Relative Efficiency In a Size Distribution of Firms

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E.E.P.A. Discussion Paper No. 2
Revised, May 1986

Prepared for
Employment and Small Enterprise Division
Office of Rural and Institutional Development
Bureau of Science and Technology
U.S. Agency for International Development
Washington, D.C. 20523
Grant No. DAN-5426-C-00-4098-0

The Employment and Enterprise Policy Analysis Project is composed of a consortium of the Harvard Institute for International Development (Prime Contractor), Development Alternatives, Inc., and Michigan State University (Subcontractors). E.E.P.A. provides technical assistance to USAID missions around the world on problems related to employment and small- and medium-scale enterprise development, and performs research on these issues for AID's Bureau of Science and Technology in Washington. For further information on E.E.P.A. contact:

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Abstract

This paper is one of a series of state-of-the-arts methodological reviews prepared for the Employment and Enterprise Policy Analysis Project sponsored by the U.S. Agency for International Development. The purpose of the paper is to review various approaches to the measurement of relative firm efficiency. An important question of public policy is how categories of firms in an industry (say, small private competitive or noncompetitive vs. large public or private competitive or noncompetitive) rank in terms of relative productive efficiency, and, what causes the differences in productivity levels? This review shows the strengths and weaknesses of various methodologies used to obtain these interfirm rankings.

A principal contention of this paper is that total factor productivity—real output per unit of all real resources expended—is the single best measure of productive efficiency. Partial productivity indexes are shown to be useful for examining questions of "labor or capital saving," but, because labor and capital are not the only scarce resources in production, partial productivity indexes do not tell the whole story about firm efficiency.

The review also indicates that firm efficiency can be divided in two components: technical efficiency and allocative efficiency. Methodologies are described for obtaining measures of interfirm levels of economic efficiency as well as differentials in these allocative and technical efficiency components. Benefit-cost ratios, profit functions, production frontiers, and Christensen-Jorgensen efficiency indexes are each considered. It is shown that benefit-cost ratios capture economic efficiency (combined allocative and technical efficiency). Profit functions, on the other hand, can be used to measure interfirm differentials in each efficiency component.

Technical efficiency differentials are best measured by "best practice" production frontier estimation techniques. The literature describing various approaches to the estimation of these frontiers indicates that different techniques yield broadly similar results. Researchers are therefore recommended to choose the simplest method. When input-output coefficients are available, the Christensen-Jorgenson index will also provide a good measure of interfirm differences in total factor productivity. This index can also be used to study changes in interfirm efficiency over time.

Whichever method is used to calculate total factor productivity, the next task is to explain the sources of interfirm efficiency differentials. Along these lines, the paper reviews regression and other methodologies to decompose the sources of interfirm technical inefficiencies. Decomposition is performed such that the causes of inefficiency as well as indications of potential policy remedies become clear.

Lastly, the paper deals with research methods to study dynamic efficiency issues. A methodology is described to decompose total factor productivity growth in three components: (1) technological progress, (2) changes in technical efficiency, and (3) output elasticity differences between the "best practice" production frontier and operations inside the frontier.

On Measuring Relative Efficiency
In a Size Distribution of Firms

Policymakers presumably are not interested in the size of enterprises *per se*, but in whether the conduct, performance, and difficulties of industries vary within different firm size classes. One reason is that policies to promote economic growth and welfare may best be administered in different ways to enterprises of different size. For example, knowledge of how the capacity to create employment or generate exports is related to particular sectors and enterprise size categories within these sectors could help policymakers to develop programs and policies to encourage enterprise groups with the highest potential for meeting planned economic targets. Economic authorities may also be interested in the size structure of industry because of the unintended consequences on market pricing and production efficiency that may result from excessive industrial concentration.

To evaluate the effect of policies and programs on interfirm performance along with the ensuing consequenses for industry growth and economic welfare, and to suggest directions for policy reform, policymakers must have some idea of the relative economic contribution of different sized enterprises--a measure, that is, of their relative social efficiency. In general, those who make policy want to make changes in the right direction (towards the ideal) without improving the profit position of enterprises with lower social efficiency more than enterprises with higher social efficiency. Thus, if one finds that the social efficiency of smaller firms is higher than that of larger firms, any existing or prospective policies or circumstances which divert resources and markets from the smaller to the larger will decrease both economic output and employment (since the K/L ratio of larger enterprises is presumed higher).[1]

When might one expect to find efficiency differentials in an industry cross-section of different sized firms? According to neoclassical competitive equilibrium theory of the firm, the long-run map of isoquants in an industry cross-section reduces to a single point. Differences in production technique, and firm size, and thus variations in efficiency do not exist (more on this in later sections). Interfirm efficiency differentials then are a short-run disequilibrium phenomenon. In the long-run, only the most efficient firms will survive, given the neoclassical assumptions.

Firm size issues and industry efficiency differentials arise when the model is extended to include returns to scale and property rights. In the latter case, a theory predicting efficiency differentials is developed on the basis of type of ownership. This theory revolves around the argument that public ownership is diffused among all members of society, and no member has the right to sell his/her share. Given these aspects of public ownership, there is little economic incentive for any owner to monitor the behavior of the firm's management. In contrast, it is argued that the ownership of private firms is concentrated among fewer individuals, each having the right to sell his/her shares; and thus the owners have incentives to scrutinize management to ensure efficiency in the production of goods and services. When economies of scale are present, a second theory of interfirm efficiency differentials emerges, based on market structures. This theory forecasts superior efficiency in markets characterized by objective competition among firms. The essential element in the theory is that in competitive markets productive effiency is a prerequisite for survival--at least for privately owned firms.

Other sources of interfirm differences in productivity levels, in addition to the mixture of effects due to ownership, limited competition and disequilibrium phenomenon, appear in the presence of market imperfections and price distortions. For example, because of differential access to resources and discriminating price policies, it is argued that smaller firms adopt production technologies that often relegate them to less efficient portions of the production frontier, due to the inability to reap the benefits of economies of scale or scope. On the other hand, distortions can also lead some firms to production scales that are "too large" and capital intensive, based on existing resource endownments (including the quality of fixed factors, namely management expertise), or, to inefficient spacial locations based on efficient transportation cost structures.

An important question of public policy is how the categories of firms (say, for example small private competitive or noncompetitive vs. large public or private noncompetitive) rank in terms of relative productive efficiency, and, what causes the differences in productivity levels. A related question is how market imperfections and price distortions effect these rankings.

The purpose of this paper is to review various approaches to the measurement of relative firm efficiency. The review sets forth and evaluates methodologies to describe interfirm differences in productivity and to isolate the sources of these differences. Results from such studies should help researchers to answer such questions as: Are small firms constrained to less efficient ranges of the "best practice" production frontier by failure to exploit economies of scale or scope? Do observed factor prices facing large and small enterprises result in significant inefficiencies? For which firms are such inefficiencies greatest? What are the characteristics of firms and industries that are furthest inside the production frontier?

The paper is organized in the following way. Section I discusses the conceptual framework used in economics to evaluate economic efficiency and to measure its various components. Section II describes a number of approaches to measure relative economic efficiency-- benefit-cost ratios, the profit function, and production frontier methods. Each methodology is described in detail together with a discussion of the particular advantages and disadvantages of its application to measuring relative economic efficiency or its components. In section II.3.4, a short discussion is presented outlining the problems of estimating efficiency indexes in the presence of systematic variation in policy-induced price distortions across firms. Section III reviews methodologies for uncovering the sources of technical inefficiency in firms. Finally, Section IV discusses an approach to measuring the change in technical efficiency of firms over time.

I. Economic Efficiency: A Conceptual Framework

Neoclassical economic theory of the firm specifies a set of conditions wherein enterprises of all sizes will have identical ratios of inputs and outputs (identical production techniques), and equal efficiency from both a private and a social point of view. That is, a set of conditions in which there will be no ideal scale of production from either the social or private perspective in long-run equilibrium, and market structure is undetermined. The conditions are as follows:

1. All enterprises have the same production functions with constant returns to scale. This implies that enterprises have the same technical knowledge and identical endowments of fixed factors of production.
2. All enterprises face the same prices in product and factor markets.
3. All enterprises maximize profits and operate in a riskless environment.

Empirical observations on enterprises in developing countries producing homogeneous outputs indicate that one or a combination of these neoclassical conditions do not hold. Within most industries a wide dispersion of factor intensities and varying average factor productivities are evident as well as an array of firm sizes, indicating that substantial differences in production technique and enterprise efficiency do exist.

The following reasons have been cited to explain the existence of different sized firms and variance in production techniques.

1. Firms that exist today began their productive activities in different time periods, and, because relative factor prices have changed over time, these firms have selected different production techniques.
2. Expecations about future factor price ratios are also important for investment decisions. At the same moment, different investors may view the future differently.
3. Existing technologies at the time investment decisions are being made may differ. Similarly firms that initiated their production in different time periods may, due to wear and tear of the machinery and additional knowledge acquired, use different combinations of inputs with the same original production process.
4. Distortions in factor prices among firms of different sizes may influence investment decisions and thus selection of production technique.
5. Knowledge of the range of existing production techniques is incomplete and imperfect and causes businessmen to make errors.
6. Enterpreneural ability differs from firm to firm. Initiative, ability, innovative spirit and so forth will lead each manager to adopt a different production technique and scale.
7. The markets faced by firms, in terms of goods and inputs, are not perfect due to low mobility, varying degrees of accessibility of different markets, and lack of homogeneity of factor services.

8. Finally, varying administrative and organizational structures among firms lead to the adoption of different decision making norms. Some examples are maximization of average income per worker, sales maximization, maximization of the managerial function, an so on.

As we will see in the discussion that follows, many of these elements may lead to interfirm differences in efficiency.

Economic inefficiency in an enterprise arises from two sources: technical inefficiency, which results from an enterprise's failure to maximize output from a given set of inputs, and allocative or price inefficiency, which stems from an enterprise's inability to select an optimal input level and/or mix, given prevailing factor prices. Allocative inefficiency has to do with managerial decision making about the allocation of the enterprise's fixed and variable factors of production--factors that are within the control of the enterprise. Allocative or price inefficiency may result from incomplete knowledge of the range of existing techniques or the quality of productive inputs; differences in the abilities, motivations and preferences of entrepreneurs in selecting the scale and technique of production; and differences in how entrepreneurs perceive uncertain choices between higher expected profits and reduced risks of doing business.

On the other hand, technical inefficiency is related to the fixed human and physical resources of the enterprise. It is more of an engineering datum. Technical inefficiency can often be explained by differences in education among entrepreneurs; inter-firm differences in non-measurable inputs, such as access to information and managerial and employee effort; and differences in vintages of technologies employed. When dealing with different sizes of enterprise, differences in technical efficiency can also arise due to increasing returns to scale (reflected in greater measured technical efficiency), product differences, and differences in technique not associated with vintage of capital equipment.

In situations where market imperfections exist and prices diverge from the social opportunity cost of factors, it is necessary to differentiate between private allocative inefficiency, where the enterprise fails to select a level or mix of inputs which would minimize private cost at a given output level, and social allocative inefficiency, where the enterprise's input mix fails to minimize social opportunity cost of production. This distinction is important, because in the presence of factor market distortions, enterprises that are efficient in keeping private costs low will in most cases violate social efficiency axioms. In developing countries, government policies and segmented markets distort product and factor market prices--minimum wage laws, taxes, subsidies, exchange rates, deficient social overhead capital--and may affect enterprises in different ways, according to their location, size, or the social connections of their managers. These distortions are frequently cited as causing enterprises to select operating scales and factor proportions that may be privately profitable, but inappropriate from a social efficiency point of view.

Finally, it should be noted that the two components of efficiency may not be totally independent. Leibenstein has noted that enterprises with market power often exhibit what he calls X-inefficiency.[2] This represents a combination of slackness in profit maximization and decreased entrepreneurial effort. In this case, X-inefficiency is a sort of luxury which is allowed to exist because of the monopolist's technological monopoly, and represents a lapse from technical efficiency. In time, monopoly profits will often attract a wave of imitators, which begins to divest the enterprise of its technological monopoly. When this occurs the manager-entrepreneur usually pays closer attention to the finer aspects of rationalization, reducing X-inefficiency. This increase in managerial effort also usually leads to increased price efficiency. Similar interactions can occur in any situation where the decreasing technical efficiency advantage of an early innovator increases the importance of price competition. Hence, in a dynamic competition model, both technical and allocative efficiency may be connected.

II. Methods for Measuring Relative Economic Efficiency

Various methodologies have been used to assess the relative economic efficiency of enterprises in studies of both industry and agriculture in developing countries. The method employed most often has been a straightforward comparison of simple output-capital ratios.[3] In reviewing these studies, David Morawetz lamented that by using partial productivity indicies the authors had overlooked, among other things, the important fact that capital is not the only scarce factor of production.[4] He went on to argue that to ensure more meaningful results, efficiency measures "should incorporate other scarce resources, such as management and skilled labor, examine total scarce-factor productivity rather than simply output-input ratios, and should evaluate factors at both market and social prices."[5] Mindfull of these problems, recent studies have applied efficiency measures that incorporate a broader range of productive factors and shadow prices. Some examples are benefit-cost ratios,[6] the cost and profit functions, and indicies of total factor productivity.[7] Benefit-cost ratios of value added to the total cost of inputs at both market and social prices have been used to measure relative economic efficiency, while total factor productivity (or technical efficiency) indices have been used to measure differences in the ability of enterprises to maximize output from a given set of factor services. The profit function has been employed to measure enterprise differences in both allocative and technical efficiency. Each of these approaches to the evaluation of economic efficiency will be assessed in the discussion that follows.

II.1 The Benefit-Cost Approach

Three different benefit-cost ratios (capturing both the allocative and technical efficiency of a firm) have been utilized in relative efficiency studies--the entrepreneurial (EBC), the private (PBC) and the social (SBC). In the first case, it is assumed that the entrepreneur's basic objective is to maximize the return on his own capital and labor inputs in the enterprise. Thus, the BC ratio most important to him is:

$$EBC = \frac{VA - [r_b\ K(b) + W_h\ L(h)]}{r_o\ K(0) + W_o\ L(0)} \qquad .1$$

where VA = Value Added

$r_b k(b)$ = the cost of borrowed capital and includes $(r_1 k_1)$, the cost of borrowed fixed capital, and $(r_2 k_2)$, the cost of borrowed working capital. (r) in the case of fixed capital is calculated on the basis of the formula:

$$r_i = \frac{i}{\dfrac{1}{1 - (1 + i)^n}}$$

where n = the expected life of the equipment and i = the rate of interest.

$W_h L(h)$ = the cost of hired labor

$r_o k(o)$ = the opportunity cost of the entrepreneur's self-financed capital. It also includes fixed and working capital costs.

$W_o L(o)$ = is the opportunity cost of the entrepreneur's labor input.

This formula can be changed slightly to calculate the implicit return to self-finance capital or the entrepreneur's labor.[8]

The private BC ratio, of interest to entrepreneurs and to other investors, relates total benefits to the costs of all resources employed by the enterprise. This ratio is expressed by the formula:

$$PBC = \frac{VA}{rk + WL} \qquad .2$$

where r = a weighted average of interest rates corresponding to the enterprise's various sources of credit, including the entrepreneur's own capital.

W = a weighted average of the wages of different skill categories, including the opportunity cost of the entrepreneur.

WL = the wage bill, including the entrepreneur's opportunity cost.

K = the firm's total fixed and working capital.

The social BC ratio is formulated using the social opportunity cost of capital and labor. In practice, analysts use a single estimate of the social opportunity cost of capital (r_s) applied to all sources of finance (since available information usually does not allow estimation of the opportunity cost of capital across different sources) as well as a sectoral average wage for each skill category as the cost to all enterprises of labor in that category. The formula is written as follows:

$$SBC = \frac{VA}{r_s k - W_s L} \qquad .3$$

If the SBC is not calculated using shadow prices to evaluate outputs or raw material inputs, it can only be used to compare BCs of enterprises in the same sector having similar input and output mixes.

When the SBC ratio is used to measure relative enterprise performance, a ratio greater than one implies that the enterprise's existence has a positive effect on the total output of the economy. A ratio of less than one implies a negative effect on the economy. If measured at market prices, as with EBC and PBC, the BC ratio reflects either the enterprise's overall profitability (given that the ratio includes all inputs), or the profitability of the entrepreneur's inputs (when the entrepreneur's capital and labor are the only inputs included). The coexistence of enterprises with different BC ratios implies that factor or product markets are distorted, that firms have differing levels of X-efficiency or risk aversion, or that measurement errors are present. In particular, a gap between PBC and SBC ratios offers some clues about the probable impact of removing capital and labor market distortions on enterprise profitability. Further, the differential is also an indicator of the extent to which market distortions explain the existence of socially inefficient enterprises.

II.2 The Profit Function Approach

While the BC ratio captures interfirm differences in economic performance, the question remains whether a group of firms is more economically efficient than another because it is more successful in responding to the set of prices it faces (price efficiency) and/or because it has higher quantities (qualities) of unmeasurable fixed factors of production, particularly entrepreneurship (technical efficiency). An approach that has been used to test for relative differences in each component of economic efficiency is the profit function.[9] The profit function specifically allows for differences in the prices of variable factors of production and in the quantities of fixed inputs. Moreover, the profit function can be used in such a way as to allow interfirm differences in the ability to equate the value of the marginal products of variable factors to their prices, that is, to maximize profits.

These efficiency elements are combined in a function of the following form (assuming a Cobb-Douglas production function):

$$\pi = A^{*} \prod_{j=1}^{m} q_j^{\alpha_j^{*}} \prod_{j=1}^{n} Z_j^{\beta_j^{*}} \qquad .4$$

Where π = normalized profits (deflated by the price of output)

q_j = real price of the j^{th} variable factor of production (deflated by the price of output);

Z_j = quantity of the j^{th} fixed factor of production;

α_j^{*} and β_j^{*} = coefficients of prices of variable factors and quantities of fixed factors, respectively;

A^{*} = a constant.

The approach to assessing relative economic efficiency is straightforward. Given comparable factor endowments, identical technology, and normalized input prices, the normalized restricted profits of two firms should be identical if they have both maximized profits. To the extent that one firm is more price-efficient, or more technical-efficient than the other, the normalized restricted profits will differ even for the same normalized input prices and measured endowments of fixed inputs.

To see this, one can write the normalized restricted profit function in more disaggregated form:

$$\pi^i = A^i G^* \left(\frac{k^i q^i}{A^i}; Z^i\right) + A^i \sum_{j=1}^{m} \frac{(1 - k_j^i)\, q_j^i}{k_j^i} \bullet \frac{\partial G^* \left(\frac{k^i q^i}{A^i}; Z^i\right)}{\partial q_j^i} \qquad .5$$

Where i = 1,2 group of firms

Equation (6) has two types of variables: group-specific variables, A^i, and k^i, and firm-specific variables, q_j and, Z_j. The group-specific parameters, A^1, and A^2, allow for neutral differences in environmental factors, managerial ability, and other nonmeasurable fixed factors of production and are thus designated group-specific technical efficiency parameters. If two groups of firms are equally technical-efficient, then $A^1 = A^2$. Next the profit function allows groups of firms to vary in terms of price efficiency, that is, in the degree to which they are successful in equating marginal products to firm-specific factor prices (q_j and Z_j), through the introduction of group-specific and variable-input-specific k_j's. If two groups are equally price efficient with respect to all variable inputs, $k_j^1 = k_j^2$, $j = 1, \ldots, M$. In terms of this notation, the null hypothesis of equal relative economic efficiency for group 1 and group 2 implies that $A^1 = A^2$ and $k^1 = k^2$. When appropriate functional forms are specified for G*, statistical tests can be devised to examine this null hypothesis.

In most empirical applications, the Cobb-Douglas logarithmic normalized profit function has been specified.[10] This is given by equations (7) and (8) below:

$$\ln \pi^1 = \ln A^{*1} + \sum_{j=1}^{m} \alpha_{1j}^{*} \ln q_j + \sum_{j=1}^{n} \beta_{1j}^{*} \ln Z_j \qquad .6$$

$$\ln \pi^2 = \ln A^{*2} + \sum_{j=1}^{m} \alpha_{2j}^{*} \ln q_j + \sum_{j=1}^{n} \beta_{2j} \ln Z_j \qquad .7$$

Where π^1 and π^2	=	actual normalized restricted profit (total revenue minus total variable cost, divided by the price of output);
$\sum_{j=1}^{m} q_j$	=	"normalized" wage rate and prices of other m inputs divided by output price;
$\sum_{j=1}^{n} Z_j$	=	quantities of n fixed factors of production.

The maintained hypothesis is that the production function is identical for large and small firms (producing homogenous products) up to a neutral efficiency parameter. This implies that the coefficients α^* and β^* are identical for each group. The error term in each equation is assumed to be caused by random shocks, divergence of the expected output price from the realized output price, and imperfect knowledge of the technical efficiency parameter of each firm.

Notice that in the equations (6) and (7) it is impossible to identify separately the A_i's and k_i's of equation (5). Only their combined effect in terms of economic efficiency is captured by the A^*_i's. In order to separate the different components of economic efficiency, the profit function must be estimated jointly with the input demand functions. The demand for each (m) variable factor of production is given by:

$$X_j = \frac{-\partial \pi}{\partial q_j} , \quad j = 1, \ldots, m \qquad .8$$

which implies the following factor-share functions:

$$\frac{-q_j X_j}{\pi} = \alpha_{ij}^{**} , \quad i=1,2;\ j=1,\ldots,m \qquad .9$$

The null hypothesis of equal price efficiency (or profit maximization) is tested by determining whether the α^*'s from the normalized profit functions (α_j^*) and factor share equations (α_j^{**}) are equal within each group.

If the hypothesis of profit maximization in each group cannot be rejected (implying price-efficiency in each), the coefficients of the functions are estimated by Zellner's method, imposing linear constraints implied by profit maximization ($\alpha_{ij}^{**} = \alpha_j^*$) and constant returns to scale (β_j's = 1) to obtain asymptotically efficient estimations. Relative economic efficiency is then tested through the null hypothesis $A^{*1} = A^{*2}$.

The profit function approach to measuring relative firm efficiency has been applied extensively to agricultural data. The conclusion of these studies is mixed. Early studies of the Indian Punjab (1950's)[11] indicate that small farms (less than 10 acres) have higher relative economic efficiency than large farms, due to greater technical efficiency. A later study (1960's) of the same area, however, revealed that small and large farms display no significant differences in relative economic efficiency, nor in price or technical efficiency.[12] The differences in results has been attributed to the modernization of Punjab agriculture in the 1960's. Relying on the early adoption of new varieties of seeds, fertilizers, and other chemical inputs, and on irrigation, large farms increased their technical efficiency, catching up with small farms in that category. A study of Northeast Chinese farmers based on 1940's data indicated that no difference in technical or allocative efficiency could be found between farms of different size.[13]

II.3 The Production Frontier Approach

Estimation of relative economic efficiency using the profit function is based upon a comparison of the "average" profit or production function for each cohort. Unfortunately, this may obscure the fact the both cohorts operate away from the most efficient "best practice" profit (or production) level. Information on the efficiency of each enterprise (or enterprise cohort) relative to best practice in the industry is lost. To obtain tnis additional information, differences between firms in achieving economic efficiency must be measured relative to a technical "best practice" frontier rather than to some "average" production function. The total factor productivity (or technical efficiency) index is utilized for this purpose. The index gives a measure of relative technical inefficiency based upon the best practice in the industry, plus it allows the researcher to decompose technical inefficiency into its various components.

Measurement of the technical inefficiency index is based on the estimation of production function frontiers. The concept of production frontiers is outlined with the help of Figure 1. Figure 1 shows a sample of firms for an industry producing a single homogenous output with two inputs K and L available at fixed prices. Output can be sold at a fixed price. The frontier production function can be characterized by the unit isoquant[14], Qo, provided that technology can be described by a linear homogenous production fucntion.

For the constant returns to scale case, an enterprise that uses the minimum combination of inputs (OR) and produces on the unit isoquant at point (R) is considered technically efficient. We can compare it with a second enterprise, having the same capital-labor ratio but using a higher quantity of inputs to manufacture a unit of output, producing at point Y. The technical-efficient enterprise produces the unit output with only OR/OY as much of each factor as the enterprise at Y. Thus the firm at Y is defined as technical-inefficient compared to R. When the prices of K and L are introduced in the form of an isocost line, AA^1, we can define a firm's allocative efficiency. This is done by comparing the prices of inputs, reflected by the slope of AA^1, to their marginal products, as reflected by the slope of the unit isoquant. In Figure 1 the enterprise producing at R^1 is allocative or price efficient, since the value marginal product of input K and the value marginal product of input L equals, respectively, the price of input K and the price of input L. The price line AA^1 is also an isocost line, which indicates the minimum cost of producing the unit output Qo at given output prices. The cost at R^1 being the same as the cost at Z, the allocative inefficiency of enterprise R can be expressed as OZ/OR.

Figure 1 also shows that allocative and technical efficiency combine to define economic efficiency. The enterprise at R is technical-efficient but price-inefficient and thus economic-inefficient. The enterprise at Z is just the opposite, technical-inefficient and price-efficient. Only the firm at R^1 is both technical and allocative efficient and thus economic-efficient. For a firm producing at y its total inefficiency OZ/OY can be decomposed into allocative component OZ/OR and the technical component OR/OY.

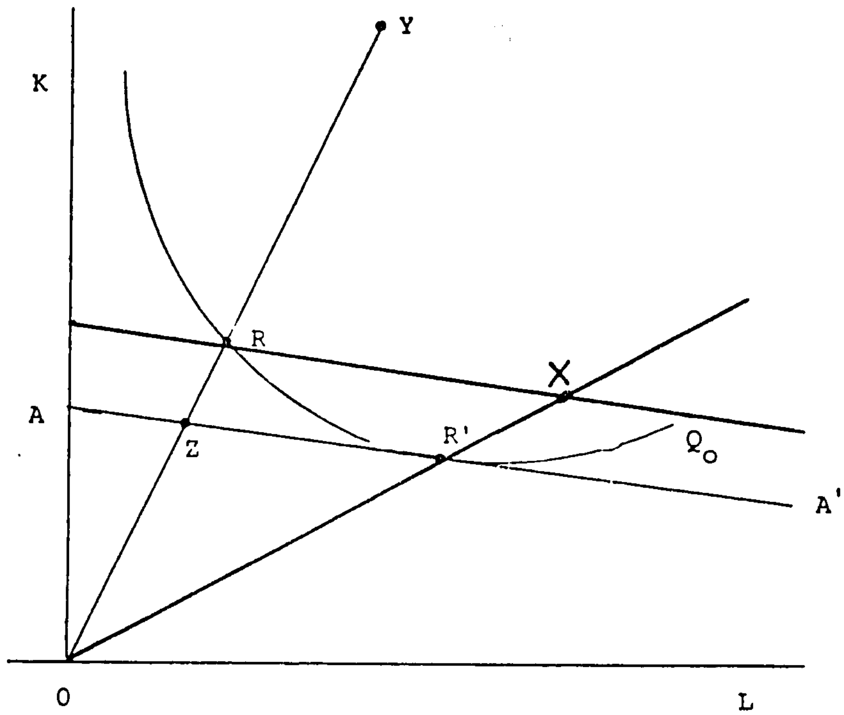

Figure 1 Technical and Allocative Efficiency

This analysis does not treat selection of the optimal level of production because, as we pointed out earlier, the scale of production is indeterminate in the case of constant returns to scale. If the constant returns assumption is dropped, optimal scale of production will be determined at the level where output price equals the marginal cost of lroduction. A firm will be on the cost frontier if it exhibits technical and allocative efficiency. A scale-efficient firm, then, is one that chooses the profit maximizing level of production.

There are several interpretations to the scatter of points in Figure 1 some of which were discussed in the beginning of this paper. Because of their importance, we will review them again. First, one explanation is that firms do not operate with the same technology. If this is the case there is no reason to investigate differences in efficiency. This is particularly important to keep in mind when interpreting many of the large firm/small firm relative efficiency studies in developing countries. Do these firms, many in the formal and informal sectors, have access to the same technology and/or produce the same product? Second, the scatter could be attributed to a sample containing firms with equipment of different vintage. The relative efficiency frontier will be different for observations belonging to different vintages; hence observations should be grouped by vintages and comparisons should be made within a vintage. Third, the different production points could be caused by the fact that some firms use the same given technology more successfully than others. This corresponds to the interpretation of Farrell and other researchers that utilize the deterministic frontier approach to the measurement of technical inefficiency disscussed below. Fourth, there is the interpretation that all firms face the same technology up to a random factor that takes into account the effects on production of measurement errors in the output variable and other random shocks outside the firm's control. In this case the resulting production frontier is stochastic and departure from the frontier reflects technical inefficiency.[15]

In 1957, Farrell introduced the concept of the technical efficiency frontier or "best practice" production function, as depicted in Figure 1.[16] He measured the degree of technical efficiency of the enterprise at Y as (OR/OY) x 100 on a percentage basis. An index of 70 percent for the firm at Y implies that k and L be reduced at a scale of 10:7, with the enterprise still producing one unit of output--provided that it "were like" the enterprise at R.[17] It should be noted that since Farrell-efficiency measures in practice rely solely on output and input quantity data, one cannot distinguish allocative from technical or scale inefficiency. In terms of Figure 1, the firms producing at R and R^1 would emerge as efficient, while the firm producing at X would be designated inefficient even though it is allocative-efficient and it achieves same degree of overall efficiency as firm R.

A number of methods have been devised to estimate the technical efficiency or "best practice" production frontier since Farrell's path-breaking work. The earliest work on frontiers assumed what could be called a "deterministic" frontier.[18] Deterministic frontiers force all observations to be on or below the frontier and hence all deviations from the frontier are attributed to inefficiency. The basic procedure is to construct the efficient unit isoquant from the observed input-output ratios by linear programming techniques. This approach imposes no functional form on the data (it does, however, assume constant returns to scale). One approximates the unknown efficiency frontier with a minimum of restrictions. Only in the case of constant returns to scale, however, does this procedure provide enough information to determine a production function. For this reason, parametric deterministic frontiers came into use where a functional form is imposed on the production function and the parameters are estimated by programming[19] or by statistical techniques.[20] In the latter case, the advatantage of the method is that if the distribution of techical inefficiency is properly specified, one can derive statistical estimates with desirable properties.

There were disadvantages to using both the parametric and nonparametric determinstic techniques, however. Analysts found that there are severe statistical problems with deterministic frontiers. In some cases, although a distrubance term must implicitly be assumed, no assumptions are made about its properties. Hence, parameters are not estimated in a statistical sense, but merely computed via mathematical programming technicques. In cases where a distrubance is explicitly included (the statistical approach to parametric deterministic frontiers), its properties have been assumed to be one-sided (non-positive) of some particular form. Specification of distrubance terms in this fashion, however, violate regularity conditions for application of maximum likelihood techniques; hence, estimation of deterministic frontiers is not completely straightforward.[21] Deterministic frontiers are also extremely sensitive to outliers. If these outliers reflect measurement errors they will heavily distort the estimated frontier and efficiency measures derived from it.

This second deficiency, the sensitivity to outliers, led to the development of probabilistic production frontiers by Timmer.[22] In this approach, a deterministic frontier is computed by mathematical programming techniques, after which supporting data points are discarded and a new deterministic frontier is computed. The process continues until the computed frontier stabilizes. The probabilistic frontier approach thus "solves" outlier problems by discarding outliers from the sample. But, since a probabilistic frontier is just a nonparametric deterministic frontier computed from a subset of the original enterprise sample, it remains vulnerable to statistical challenges against deterministic frontiers--namely, that since it is computed rather than estimated hypothesis testing is impossible.

In the last few years, econometricians have attempted to ameliorate the problems associated with both deterministic and probabilistic production frontiers by specifying a stocastic "best practice" production frontier.[23] In this specification, the output of each firm is bounded above by a frontier that is allowed to vary randomly across firms and thus is stocastic. Such a technique permits firms to be technically inefficient relative to their own frontier rather than to some sample norm. Differences between enterprises in the level of "best practice" production frontiers is accounted for by the effects of exogenous shocks (good and bad) beyond an individual enterprise's control plus measurement errors. The distrubance is specified such that it has two parts: a symmetric (normal) component capturing randomness outside the control of the enterprise and, second, a one-sided (non-positive) component capturing randomness under the control of the enterprise (i.e.

inefficiency). Estimation of the model provides a set of efficiency values such as (1) an average efficiency index for the sector; (2) an expected efficiency index for each observation (firm) relative to the stochastic frontier; and (3) a measure, $\lambda\ u^{\sigma}/\ v^{\sigma}$, indicating whether most of the variance from the frontier is due to randomness or to inefficiency.[24] Estimation of the stocastic frontier is thus amenable to the usual types of statistical inference. The analyst may choose, depending upon the statistical properties of the case under examination, between estimation of stocastic factor demand frontiers (when excess of factor demand above its frontier is solely due to technical inefficiency), a stocastic cost frontier (measuring the extra cost of producing below the production frontier, that is the cost of technical inefficiency), and the stocastic production frontier, from which all the other frontiers are derived.[25]

Although the statistical properties of stochastic frontiers are preferable to those of deterministic frontiers, studies of relative firm efficicency have exclusively utilized the latter methodology. The reason is that until recently stochastic frontiers did not generate values for each observation permitting the analyst to evaluate relative efficiency between firms. This problem has been resolved in the last few years since Jondrow et al derived estimates of expected efficiency at the firm level for the stochastic frontier model.[26] One drawback remains, however. The correction factor required to obtain a consistent estimate of the efficiency term of the stochastic frontier necessitates an estimate of the third central moment of the composite error. If tne model is correct, the sample value of this third moment is negative. If the sample value of this third moment is positive, however, the estimation procedure breaks down.[27] Thus, a few outliers arising from measurement errors could be positive and the correctly specified model cannot be estimated. In the statistical approach to deterministic frontier estimation, outliers can create bias of unknown consequences but the model can be estimated.

II.3.1 A Summary Catalog of Production Frontier Estimation Techniques

In selecting a frontier production model our discussion calls attention to three issues that arise: choice between alternative frontier model specifications, including deterministic models (linear programming and statistical deterministic) and stochastic models, the specification of the functional form of the production function, and selection of error term structure to be added to the production relation. The nature of the error term will determine the characteristics of the measures of technical inefficiency generated by the estimates, as well as the technique of estimation of the production function parameters. Below we set out a catalog of the alternative estimation techniques for production frontiers based on the Cobb-Douglas functional form to highlight the differences in methodologies.[28]

(i) Deterministic Frontier: The Linear Programming Method

Production relation $Q = f(x_j; \beta)\, e^{-U} \quad U \geqq 0$ .10

where (X) is a matrix of observations on factors of production, (β) is a vector of production function parameters, and (U) is a vector of disturbances.

Unlike estimates of the "average" production function for a set of observations, which specify (U) to be distributed independently and identically, N $(0, \sigma^2)$, frontier estimators specify (U) to have a negative expectation reflecting the presence of technical inefficiency in production. Once the error term (and functional form, here f(X) is Cobb-Douglas) has been specified the parameters of the frontier function can be computed using linear programming--that is, by minimizing the linear sum of the values of the residuals, subject to the constraint the each residual be non-positive (i.e. that all observations lie on or below the frontier.)

$$\text{Minimize:} \quad \sum^{m} U_j^{2}$$

$$\text{Subject to:} \quad \beta_o^* + \beta_1^* X_{11} + \ldots \beta_n^* X_{n1} \quad Q_1 \qquad .11$$

$$\beta_o^* + \beta_1^* X_{1m} + \ldots \beta_n^* X_{nm} \quad Q_m$$

$$\text{and:} \quad \beta_o^* \ldots \beta_n^* \quad 0$$

$$\text{and where:} \quad U_j^* = \beta_o^* + \beta_1^* X_{1j} + \ldots \beta_n^* X_{nj} - Q_j$$

The estimated production surface ($\beta_o \ldots \beta_n{}^*$) depicts a "best practice" frontier or envelope. The technical inefficiency of each observation can be calculated directly from the vector of residuals, since the error term represents technical inefficiency. Thus, the ratio of the observed output of an enterprise to the efficiency frontier output provides the technical efficiency index, TE, (the magnitude being less than or equal to one.

$$TE_j = \frac{Q_j}{Q_j^*} \qquad .12$$

$$\text{where } Q_j^* = \beta_o^* + \beta_1^* X_{ij} + \dots \beta_n^* X_{nj}$$

(ii) Deterministic Frontier: The Statistical Method

$$\text{Production relation} \quad Q = f(X_j ; \beta)\, e^{-U} \quad U \geqq 0 \qquad .13$$

As in the linear programming case, the model to be estimated is linear in parameters and is given by:

$$\ln Q = \beta_o + \beta_1 \ln X_{1j} + \dots \beta_n \ln X_{nj} + E \qquad .14$$

Estimation of the efficiency indexes is accomplished by first specifiying the characteristics of the distribution of the error term. Authors have used the parameters of the one parameter Gamma distribution and the exponential distribution of Gamma. Next, maximum likelihood estimates or COLS estimates (corrected ordinary least squares estimates) are derived. The technical efficiency index is formed as before:

$$TE_j = \frac{Q_j}{{}^{*}Q_j^{*}} \qquad .15$$

where ${}^{*}Q^{*}$ is obtained using corrected ordinary least squares estimation in most studies. TE_j is equal to ${}^{*}U^{*}$, the residual obtained from the COLS estimation procedure.

(iii) Stochastic Frontier

Production relation $Q = f_i(X_j;\ \beta)\ e^{V} \bullet e^{-U} \qquad U \geq 0$ .16

Where (e^{-U}) is the inefficiency term and (v) is a random variable that takes on values in the range $(-\infty, +\infty)$

The model, as in the other cases, is linear in parameters:

$$\ln Q = \beta_o + \beta_1 \ln X_{1j} + \ldots \beta_n \ln X_{nj} + E \qquad .17$$

Where $E = v - U$, (v) is assumed distributed normally and (U) can be assumed to take on different distributional characteristics (exponential, half-normal).

As in the case of the statistical deterministic frontier, estimation of the parameters of the production frontier is accomplished by the COLS method. A measure of the relative variability of the two sources of error is given by:

$$\lambda = \frac{\sigma_u}{\sigma_v} \qquad .18$$

To compare levels of efficiency across observations (i.e. relative firm efficiency), one forms the conditional distribution of (U_i) given E_i,

$f(U_i/E_i)$:

$$f(U_i/E_i) = \frac{f\,(U_i, E_i)}{f(E_i)} \qquad .19$$

and uses the mean of this distribution as a point of estimate of (U).

II.3.2 Comparing Alternative Frontier Model Specifications

Several studies have compared these different approaches to the estimation of production frontiers and technical inefficiency indexes. Van der Broeck et al, in 1980, utilized a panel of 28 Swedish dairy plants to compare the programming, statistical and stochastic approaches.[29] Kopp and Smith, in 1982, studied cross-section data from 43 steam electric generating plants.[30] Each of these investigations compared alternative formulations of the production function (Cobb-Douglas, CES and translog) together with the same three production frontier estimation approaches. More recently, Corbo and de Melo used the 1967 Chilean manufacturing census, containing 43 manufacturing sectors classified at the four digit ISIC level, to evaluate different error specifications over the range of production frontiers (linear programming, statistical, and stochastic), using the Cobb-Douglas functional form.[31] Since the results of all these investigations are similar, the Corbo-de Melo conclusions are reported here.

In essence, the model comparisons indicate "that different frontier approaches to measuring technical inefficiency yield broadly similar results."[32] This conclusion is precisely true for firm level efficiency estimates within sectors. For cross-sector comparisons of efficiency, results <u>are</u> sensitive to selection between statistical and stochastic formulations. But in general, choice of different error structures and different deterministic models have very little impact on the measurement of inefficiency. The one result in Corbo-de Melo that differed somewhat from other studies is that in approximately half of the manufacturing sectors investigated the stochastic frontier could not be estimated because the skewness of the distibution of the overall residual had the wrong sign (i.e., the sample value of the third moment was positive.)

II.3.3 An Alternative Total Factor Productivity Index

As indicated in the previous sections, the best single measure of productive efficiency is total factor productivity--real output per unit of all real resources expended. When input-output coefficients are available for firm size cohorts within an industry the Christensen-Jorgenson index can be used to obtain this metric rather than estimation of production frontiers.[33] The index is formulated in the following way:

$$\ln (TFP_k / TFP_l) = \sum_i^m \left(\frac{R_{ik} + R_{il}}{2} \right) \ln (Y_{ik} / Y_{il})$$

$$- \sum_i^n \left(\frac{S_{ik} + S_{il}}{2} \right) \ln (X_{ik} / X_{il}) \qquad .20$$

where k and l = different firm size cohorts

y'$_i$s = output indexes

x'$_i$s = input indexes

R'$_i$s = output revenue shares

S'$_i$s = input cost shares

i'$_i$s = denote individual outputs or inputs

Diewert has shown that this equation is the exact index procedure which corresponds to a homogenous translog production or transformation function.[34] Caves and Christenson have further shown that no restrictions of separability or neutral technological change are implicit in the formula.[35]

In the equation, the revenue shares are used as estimates of the elasticities of total cost with respect to the individual outputs. This procedure is satisfactory only if the price of each output is equal to marginal cost of production. If it is widely accepted that prices for the industry (or firm size cohort) being investigated do not reflect marginal costs of production, estimated output elasticities should be used in place of revenue shares. It should be noted that the formula can be used for time-series as well as cross-section analysis. In the case of time-series analysis indexes K and l are integrated as adjacent time periods rather than different firms or industries.

In his study of relative efficiency in Korean large and small enterprises, Ho reformulates the Christensen-Jorgensen index as follows:

$$\frac{A_S}{A_L} = \prod_{i=1}^{m} \left(\frac{VA_S/I_{iS}}{VA_L/I_{iL}} \right)^{\alpha_i} \quad ; \qquad \sum_{i=1}^{m} \alpha_i = 1 \qquad .21$$

Where A_s is the total factor productivity of small plants, and A_L the total factor productivity of large plants. VA_s = the value added produced by small plants, VA_L = the value added produced by large plants, I_{iL} = the ith factor of production used by large plants, and I_{is} = the ith factor used by small plants, and α_i's = the factor shares (or factor weights).

Although the approach is necessarily crude compared to the frontier methods, these total factor productivity indexes offer a check on the results of more sophisticated techniques. It has the advantage that the necessary indicies are relatively easy to calculate and depend on few assumptions concerning underlying production relationships. As in the case of BC ratios, the TFP ratio must be adjusted for differences between actual factor prices and opportunity costs as well as any differential impact of trade protection on value added in large and small enterprises.

Finally, it should be noted that there are several reasons why TFP ratios may result in biased efficiency measures for different size classes of firms. In contrast to large firms, small firms are more likely to under-report their value added, use lower quality labor, have a lower rate of capacity utilization, and operate in more competitive conditions. All of these elements would show up in the TFP ratios as lower efficiency. On the other hand, there may also be some elements that bias the economic efficiency measures in favor of small firms. In particular, capital may be understated to a greater extent for small than large enterprises.

Using the TFP ratio approach on manufacturing data from Korea and Taiwan, Ho found that enterprises in size categories below 100 workers were relatively most efficient in a limited number of industries, and in half these cases the most efficient size is the "medium" size category of 50-99 workers. In addition, the employment impact of these industries, particularly those that were efficient for enterprises with fewer than fifty workers, was limited. "It would appear from the Korea and Taiwan data that establishments with fewer than fifty workers cannot be relied upon to generate a large amount of employment efficiently."[37] In part this is because small enterprises are found to be efficient in only a few industries, and in part because the few industries where small establishments are efficient they do not absorb large numbers of workers. In Korea, Ho found that many of the most efficient large industries were also among the most labor-intensive. "This evidence lends support to the observation that in many industries large enterprises are not only more productive but also more labor intensive than small enterprises."[38]

II.3.4. A Note on the Estimation of Technical Inefficiency With Systematic Variation in Policy-Imposed Price Distortions Across Firms Within a Sector.

Policy-induced price distortions can effect estimation of technical inefficiency when production frontier techniques are employed. If variations in effective rates of protection across firms within a sector exist, for example, the estimated coefficients of the frontier model will be biased. When variations in effective rates across firms are positively (negatively) correlated with capital (labor) uses then not only will the elasticity estimates be biased, but the estimated variances of the error will be upward biased. In the case of an exponential error structure specifiation, variation in effective rates will result in a downward-biased estimate for expected inefficiency.[39]

This problem can be investigated as a special case of specification error. In the case of the Cobb-Douglas functional form, the estimated function is:

$$\ln Q^D_i = \alpha^D + \beta^D \ln K_i + \gamma^D \ln L_i + v^D_i - U^D_i \qquad .22$$

Where Q^D_i is value added measured at domestic prices which includes protection.

The correct model should measure value added at international prices, as in equation (23).

$$\ln Q^I_i = \alpha^I + \beta^I \ln k_i + \gamma^I \ln L_i + v^I_i - U^I_i \qquad .23$$

The misspecification of the dependent variable is due to the effective rate of protection (ERP_i) in sector i.

$$Q^D_i = (1 + ERP_i) Q^I_i \qquad .24$$

The estimated model is incorrect because it has left out a variable ($1 + ERP_i$). By including this variable in the estimated model, we have:

$$\ln Q^D_i = \alpha^I + \beta^I \ln K_i + \gamma^I \ln L_i + \ln (1 + ERP_i) + v^I_i - U^I_i \qquad .25$$

The impact on the estimated coefficients and residual of a left-out variable will depend on the degree of correlation between included variables and the left-out variable. Thus the degree of bias in the expected value of the estimated coefficient will be:

$$E(\beta^D) = \beta^I + P_{42}$$
$$E(\gamma^D) = \gamma^I + P_{43} \qquad .26$$

Where P_{42} and P_{43} are the coefficients of ln K_i and ln L_i respectively when (1 + ERP_i) is regressed on each of the included variables.

If ln (1 + ERP_i) and the included variables are positively (negatively) correlated as has usually been found, then P_{42} 0, P_{43} 0, and γ^d is upward biased (β^D) is downward biased). In the case of the variance of the estimated model $E(\sigma^2_D) > \sigma^2$. Where $\sigma^2 = V(V) + V(U)$ and σ^2_D is an estimator of the variance obtained from the misspecified model. Therefore, the estimated variance of the model with the left out variable is upward biased. This will have implications for tests of significance.

What has been outlined here is the case of possible estimation bias for a sectoral measure of efficiency. If effective rates of protection and other policy-induced price distortions (e.g. factor market distortions) vary systematically across firms within a sector (say, small firms vs. large firms), firm level measures of technical inefficiency will also be biased differentially between the groups in the same ways.

III. Evaluating the Sources of Technical Inefficiency In Different Firm Size Cohorts

Empirical indexes of technical inefficiency should be interpreted quite broadly as embodying both the consequences of an analyst's ability to measure traditional inputs with ideal accuracy and the effect of non-measured inputs on the productivity of enterprises. Attempts to explain "sources" of inefficiency, therefore, generally consist of multiple correlation techniques in which enterprise attributes reflecting characteristics of measured inputs (e.g. labor force skills, levels of capacity utilization) along with variables thought to affect the quality or quantity of unmeasured inputs (entrepreneurial characteristics) are tested for their relationship to relative levels of technical efficiency.[40] The strategy adopted in assessing the sources of inefficiency in firms size cohorts is thus to control, as far as possible, variations in characteristics of measured inputs among enterprises, and then to test whether size has an impact on relative efficiency independent of variations in other measured enterprise qualities. The analyst in these examinations is implicitly adopting a hypothesis that firms differ in a systematic way according to size in the quality and quantity of non-measured inputs.

An example of this process follows, utilizing a study of firm size and technical efficiency in India.[41] Farrell indicies for enterprises of different sizes, (see Table 1) which have been calculated by the linear programming production frontier approach (a translog functional form was assumed), are first subjected to a pairwise analysis of variance between the smallest class and all other size classes; this analysis is to test for the statistical significance of differences between Farrell indicies of each size class with the different industries. The null hypothesis is that there is no significant difference between the mean levels of technical efficiency between pairs. In the case of Table 1, it was found that in three of the four industries (shoes, printing, soap) there was little statistically signficant variation of technical efficiency with firm size. Machine tool manufacturing is the only industry in which there was a significant difference in the mean indicies between the smallest category and all succeeding size classes.

These results are not surprising because size may act as a proxy for a number of attributes of the enterprise, all perhaps offsetting in their effect on technical efficiency. Data on as many enterprise characteristics as possible must be included in the analysis to obtain a more complete test of the relationship between firm size and efficiency. For example, information regarding measurable levels of entrepreneurial education and experience, age of the enterprise and vintage of capital stock, labor turnover and employee experience, and indicators of capacity utilization would be helpful. The enterprise-specific Farrell indices can then be regressed on these additional variables to try to hold constant (control for) as many of the enterprise's key characteristics as possible.

In the India study, four regressions were run for each industry--the dependent variable in each regression being the logarithm of the Farrell index. The first two regressions provide information on

TABLE 1

Farrell indices for four Indian industries by size of firm (N = number of workers).

	Overall	$N\le 5$	$5<N\le 10$	$10<N\le 25$	$25<N\le 50$	$50<N\le 100$	$N>100$
Shoes							
Mean	0.424	0.360	0.452	0.415	0.489	—	0.493
Standard deviation	(0.228)	(0.215)	(0.267)	(0.200)	(0.274)	—	(0.167)
Minimum	0.069	0.069	0.104	0.137	0.175	—	0.346
Observations	99	24	25	33	10	—	7
Printing							
Mean	0.645	0.797	0.569[a]	0.689	0.700	0.591	0.565
Standard deviation	(0.179)	(0.101)	(0.151)	(0.178)	(0.214)	(0.229)	(0.157)
Minimum	0.373	0.629	0.373	0.414	0.405	0.429	0.444
Observations	66	6	26	19	10	2	3
Soap							
Mean	0.579	0.578	0.548	0.602	0.647	0.560	0.668
Standard deviation	(0.185)	(0.213)	(0.206)	(1.75)	(0.046)	(0.155)	(0.032)
Minimum	0.313	0.320	0.313	0.346	0.615	0.388	0.665
Observations	48	9	19	13	2	3	2
Machine Tools							
Mean	0.688	—	0.547	0.672[a]	0.638[a]	0.691[a]	0.773[a]
Standard deviation	(0.119)	—	(0.036)	(0.129)	(0.077)	(0.125)	(0.137)
Minimum	0.500	—	0.516	0.500	0.553	0.563	0.610
Observations	78	—	4	28	24	9	13

[a] Significantly different -- at the 95 percent confidence level -- from the mean for the smallest size class

Source: Page (1984) Firm Size and Technical Efficiency the sources of inefficiency in each industry, exclusive of enterprise size. Having thus controlled as far as possible for the effects of other measurable contributions to the technical efficiency of firms, the final two regressions represent tests for the effect of firm size on relative technical efficiency. In this case, including the size variable with other omitted variables associated with scale did not substantially change the results. There continued to be no strong association between enterprise size and relative technical efficiency in three of the four industries. The positive relationship in the machine tools industry is explained by the effects of plant level economies of scale.

III.1. Sources of Technical Inefficiency and Policy Intervention

An alternative method for identifying the sources of technical inefficiency has been utilized in a recent study of the textile industry in the Philippines.[42] The Philippines study was not directly interested in relative efficiency of enterprises; rather it examined relative efficiency of different technologies in the textile sector. However, the study's methodology, which was used to examine the nature of efficiency differentials, could be applied with the same success to an investigation of the relationship between enterprise size and relative technical efficiency.

Of particular interest is the method's procedure for identifying individually the impediments to efficient production, making it possible to obtain both an improved insight into the underlying reality as well as indications of potential policies to remedy these deficiencies. The resulting disaggregation of a summary technical efficiency measure into its components is one which roughly corresponds to categories of potential policy intervention: those that affect efficiency indirectly by altering the functioning of the national economy, those that directly affect the industry as a whole, those that influence the technical competence of the individual enterprise, and those whose main impact is on the task-level efficiency of individual workers.

First, at the national level, the entire incentive structure exerts an important influence on the desire (and necessity) of an enterprise to strive for high efficiency--particularly policies affecting international trade, formal and informal financial markets, labor markets and commodity prices. Second, the efficiency of individual enterprises will be affected by characteristics of specific industries such as the industrial organization of the sector. Industrial concentration may, for example, affect cost structures and the diffusion of technology among enterprises. Further, if the growth of an industry has been artificially encouraged by trade policies or financial policies, its productive capacity may exceed the demand of the domestic market. Given this situation, if it is incapable of producing at sufficiently low cost to export, it will operate at higher than necessary average cost. Third, at the firm level, a large number of technical skills affect efficiency. For example, adequate blending of raw fiber at the beginning of the production process and good humidity control in spinning and weaving are important to achieve high efficiency with any set of machines in a textile enterprise. Fourth, task-level efficiency will depend upon workers' skills and motivation, which are affected by the internal incentive structure of enterprises, the quality and intensity of supervision, and general organizational characteristics such as whether workers feel well-treated.

Unfortunately, a decomposition of the sources of productive inefficiency using these categories, although crucial to policy evaluation, can indicate only the proximate, not the ultimate sources of industrial inefficiency. Thus, with respect to task-level productivity, the immediate locus of low worker efficiency may be inadequate training by the enterprise. However, the enterprise's own cost of training could be decreased by an improved national education system. Additionally, the adverse incentive effect of national protectionist trade policies may manifest itself at the industry and enterprise level in the form of excessive product differentiation and inadequate technical knowledge. Nevertheless, in spite of these complex causal links, decomposition can be useful in identifying direct policy interventions as well as in identifying specific technological or economic policies to induce the longer-run benefits to be obtained from general liberalization.

A production theoretic framework is employed to implement the decomposition. Assume that an enterprise, A, is being compared with a "best practice" production frontier, BP.[43] Variations in the labor/capital ratio are assumed to be possible in both the best practice and the actual observations according to the production function:

$$Q = \prod_i P_i K^{\alpha} L^{1-\alpha} \qquad i = 1,2,3,4 \qquad .27$$

where the P_i are neutral efficiency indicies reflecting (1) national, (2) industry, (3) enterprise, (4) and task-level efficiency. In the Cobb-Douglas formulation, labor productivity is given by:

$$Q/L = \prod_i P_i \, (K/L)^{\alpha} \qquad .28$$

The difference between best practice and observed labor productivities depends on differences in both the efficiency indicies and the capital intensities, or:

$$\frac{(Q/L)_A}{(Q/L)_{BP}} = \prod_i \left(\frac{P_A}{P_{BP}}\right)_i \left(\frac{(K/L)_A}{(K/L)_{BP}}\right)^{\alpha} \qquad .29$$

If the predicted ratio of actual to best practice labor productivity after the adjustment for differences in capital intensity and P_1 P_2 P_3 is denoted by q^*, task level efficiency can be calculated as:

$$P_4 = \frac{(Q/L)_A / (Q/L)_{BP}}{q^*} \qquad .30$$

The results of the calculations using these equations will indicate for each enterprise (or class of enterprises) the four contributing factors to technical inefficiency. Values for a particular efficiency index (national, industry, enterprise and task-level efficiency) less than unity indicate that the factor in question reduces the efficiency of the operating enterprise below best practice, while values of unity indicate performance equal to best practice.

Pack obtains results using equations 28, 29 and 30 for the Philippines cotton spinning and weaving industries. He finds that the failure of Philippine spinning plants to achieve "best practice" (defin by developing country technology) levels of product specialization is a major source of low technical efficiency, reducing it by twenty percent Given that the size of the Philippine domestic market, to say nothing o exports, is sufficiently large to permit considerable product specialization by plants, rationalization of the product mix could, by itself, reduce operating costs of conventional ring spinning plants by a average of 20 percent. The technical capacity of spinning plants, as measured by firm-specific technical efficiency, varies considerably amon the various vintage groups. The major source of high technical efficiency of the lowest cost plants lies in their mastery of the variou production engineering activities. In comparison, firms using new vintages fall short of best practice standards because they fail to use the technology properly. An unexpected result of the study was the relatively high task-level efficiency found in spinning plants. Task-level efficiency, while conveying information about the performance of individual workers, also measures important aspects of managerial competence in areas ranging from supervision to the provision of an atmosphere of well being. Hence, shortfalls in task-level efficiency provide an upper bound measure of the skill deficiencies of individual workers.

These results on the source of low technical efficiency in spinning allow the policymaker to be optimistic about prospects for improving Philippine efficiency. Of the three sources, the most important for all plants is the inability to obtain adequate specialization. This is an area amenable to direct policy intervention. Rationalization of the industry's structure, combined with import liberalization, can be designed to acheive greater efficiency from longer production runs. In contrast, the deficiency that is likely to be the most difficult to correct -- task-level efficiency -- is relatively small. Correcting low task-level efficiency is a long-term effort, requiring additional efforts at recruiting, training, better management, and the introduction of wage incentive systems, none directly open to alteration by government policy interventions.

IV. The "Best Practice" Production Frontier and Total Factor Productivity Change

In sections II, III, and IV, measures and explanations of technical inefficiency are described for a static situtation where technical progress and technical efficiency are unchanging. Once the "best practice" production frontier is established for any set of observations, the amount by which measured total factor productivity is less than this static potential is defined as technical inefficiency. The best practice frontier and the technical efficiency of firms are assumed constant over time. In a dynamic world, however, total factor productivity growth will be composed of both technical progress--that is, changes in the production frontier--and technical efficiency growth--defined as changes in the way a given technology is utilized.[44]

In developing countries such a distinction between technical progress and changes in technical efficiency is particularly important for the study of relative firm efficiency and general productivity performance. Given a level of technology, resource allocation may be required to reach the production frontier level of technical efficiency over time. Further, there is accumulating evidence that technical efficiency growth due to such "technological mastery" is substantial in developing countries, and may out weigh gains from technological progress.[45]

Although technological change and technical efficiency share a common methodological basis in the production function, applied work in these fields has evolved independently. In a recent study of total factor productivity growth in Yugoslavia, Nishimizu and Page propose a methodology that unites the empirical work in both areas. They decompose an equation for the rate of total factor productivity (TFP) change into several components as shown below:

$$\dot{g}(z) = \dot{g}_{s^*,t^*}(z) + \dot{e}_{s,t} + \left[g^z_{s^*t^*} - g^z_{s,t}\right] \dot{z}_{s,t} \qquad .31$$

Where (*) denotes BP production frontier variables, the dot over variables denotes logarithmic time derivatives, (s) equals the individual firm observation, (t) equals the time period, and (z) is a vector of production inputs (capital, labor, materials).

In this formulation, $\dot{g}_{s,t}(z)$, is the conventional rate of change of TFP for firm (s) in time period (t). On the right-hand side of the equation this rate of change is decomposed into three variables. First, $\dot{g}_{s^*,t^*}(z)$, represents the rate of technological change of the production frontier. This is, in essence, the "true" rate of technological progress. Over any given set of firms the frontier production function provides information on the subset of firms which define the technological state of the art. The second component, $\dot{e}_{s,t}$, equals the changes in relative efficiency with which known techniques are employed. The way Nishimizu and Page have defined it, this element represents the rate at which any observed firm is moving toward or away from the production frontier. ($\dot{e}$) can be referred to as the rate of technical efficiency change. By definition ($\dot{e}$) for a firm that sustains best practice over time must equal zero. For others it will be positive or negative as the firm experiences a decreased or increased gap between its potential to actual efficiency levels. It is possible for a firm to be on the frontier at one time and off it at another. In such cases ($\dot{e}$) equals the sign appropriate to the direction of movement relative to the shifting frontier. Finally, the third component of the rate of change in TFP is given by:

$$\left[g^z_{s^*,t^*} - g^z_{s,t}\right] \dot{z}_{x,t} \;.$$

This represents the fact that for any given level of inputs, a firm that is not on the production frontier may be required to change the output elasticities of its productive factors to reach its potential output.

g^{z}_{st} represents the vector of output elasticities of the firm off the production frontier and $g^{z}_{s^*t^*}$ represents the vector on the frontier. Thus, the Nishimizu-Page equation represents a decomposition of the conventional measure of TFP change into that part of the change due to technological progress, that part due to a change in technical efficiency, and finally that part due to output elasticity differences between the production frontier and off the frontier.

To estimate the magnitude of these components various production frontier estimation techniques can be utilized, as described in section II.3 of this paper. Nishimizu and Page estimate a deterministic production frontier using linear programming. A translog functional form is specified and constant returns to scale, monotonicity and concavity are imposed as additional restrictions. The usual procedure to obtain parameter estimates is first to estimate the frontier parameters for each firm (or sector, depending on the level of analysis). The rate of technical progress is then computed by combining frontier parameters with observed input levels for each year, taking simple averages of consecutive time period pairs. Thus, for firms on the production frontier at different points in time, the translog frontier is given by:

$$\ln X^*_{s,t} = (\alpha^*_o + \alpha^*_t\, t + \tfrac{1}{2}\, \beta^*_{tt}\, t^2) + \sum_m (\alpha^*_m + \beta^*_{mt}\, t)$$ .32

$$\ln z_{ms,t} + \tfrac{1}{2} \sum_m \sum_n \beta^*_{mn} \ln z_{ms,t} \ln z_{ns,t}$$

Where α^*_t = the rate of technological progress

β^*_{tt} = the rate of change of technological progress, +, -, 0 depending on whether there is acceleration

β^*_{mt} = the change in output elasticity for each factor i .ut over time. This takes the sign +, -, 0 for each factor depending on whether bias of technical change is factor using, saving, or neutral.

$x^*_{s,t}$ = the best practice potential output for firm (s) at time (t).

To estimate the rate of technological progress, as described above, parameters from this estimated frontier function are combined with observed input levels in the following equation:

$$\frac{\partial \ln X_{s,t}}{\partial t} = \alpha_t + \beta_{tt}\, t + \sum_m \beta_{mt} \ln z_m$$ .33

Next, the <u>level</u> of technical efficiency, as defined by

$$e_{s,t} = x_{s,t} \,/\, x^*_{s^*,t^*}$$

Next, the <u>level</u> of technical efficiency, as defined by can be obtained as the antilog of the slack variables in the linear programming constraints. The <u>rate of change</u> in technical efficiency is approximated by taking log differences of successive time periods. The fourth step of the procedure is to estimate the differences between off-frontier and on-frontier elasticities. However, since the off-frontier output elasticities are unobserved, this step is skipped. Estimation then moves to the final procedure which is to compute the TFP rate of change as the rate of technological progress plus the rate of change of technical efficiency. The rate of TFP computed in this fashion will be unadjusted for differences between unobserved off-frontier and on-frontier output elasticities.

The importance of this methodology is that is allows the researcher to examine the rate of total factor productivity change over time as well as its various components in individual firms and in cohorts of large and small producers. In developing countries which borrow technology extensively from abroad, failure to acquire and adapt technology to new international standards will be reflected in lack of technological progress at the industry and firm frontier. This problem can be assessed in cohorts by estimating frontiers for each group. Lack of technological progress is indicative of failures in investment planning and implementation, access to new technology and knowledge about new technology, and a policy environment which does not facilitate acquisition and adaptation of new foreign technology. Similarly, changes in technical efficiency across time periods and among individual firms indicates the success or failure of a number of important dimensions of economic policy (see section III) and industrial planning.

Summary and Conclusions:

Policymakers are interested in whether the conduct, performance, and difficulties of industries vary within different firm size classes. One reason is that policies to promote economic growth and welfare may best be administered in different ways to enterprises of different size. Another reason is that there may be unintended consequences on market pricing and production efficiency from an excessively large-firm dominated industrial structure. Recently, a third argument has been proposed to policymakers for paying attention to the size structure of industry. A small but vocal group of development researchers and practitioners advise that a shift in the size structure of enterprise can increase output, because small firms in many industries have higher total factor productivity than large firms, and increase employment, because small firms in many industries have higher labor to capital ratios.

A key element in these presumptions is information about relative firm efficiency. To evaluate the influence of policy on different sized enterprises together with the ensuing consequences for economic growth and welfare, and to suggest directions for policy reform, decisionmakers need some knowledge about the relative economic contribution of different enterprises. The aim of this paper has been to review the theoretical foundations and derivative research methodologies for measuring relative economic efficiency. The paper also examines methods to isolate the sources of efficiency differences between firms and methods to assess dynamic issues, such as the rate of total factor productivity change, changes in technological progress and changes in technical efficiency over time.

The first measure of relative firm efficiency examined in section II of the review was the partial productivity index. This metric measures the ratio of output or value added to some individual input such as capital or labor. Such indices, it was shown, can be useful for examining questions of "labor or capital saving." However, since labor and capital are not the only scarce resources in production, partial productivity indicies do not tell the whole story about firm efficiency. To address this concern total factor productivity analysis was developed. Various methods for obtaining total factor productivity (TFP) indices were treated in section II.3--we review these later.

First, an alternative attempt to accomplish the same correction that can be obtained through TFP analysis, but with simpler methods, is the benefit-cost ratio. This measure, unlike TFP indexes which estimate technical inefficiency, captures economic efficiency differences among firms (combined allocative and technical efficiency differences). The benefit-cost ratio compares value added in a firm (or sector) to the total cost of inputs at both private and social prices. When social prices are used, the measure (called a social benefit-cost ratio) can show whether or not the existence of an enterprise has a positive (negative) effect on the total output of the economy. When actual prices are used the private benefit-cost ratio may be used to compare the productivity of firms having similar mixes of inputs and outputs. The coexistence of enterprises with different benefit-cost ratios implies that factor or product markets are distorted, that firms have differing levels of X-efficiency or risk aversion, or that measurement errors are present. In particular, a gap between private and social ratios offers some clues about the probable impact of removing capital and labor market distortions on enterprise profitability.

While the BC ratio captures interfirm differences in economic performance, the question remains whether a particular group of firms is more economically efficient than another because it is more successful in responding to the set of prices it faces (price efficiency) and/or because it has higher quantities (qualities) of unmeasurable fixed factors of production, specifically entrepreneurship (technical efficiency). An approach which can be used to measure and separate interfirm differences in each efficiency component is the profit function. However, estimation of relative economic efficiency using the profit function is based upon a comparison of the "average" profit or production function for each cohort (large vs. small enterprises). Unfortunately, this may obscure the fact that both cohorts operate away from the most efficient "best practice" profit (or production) level. Information on the efficiency of each enterprise relative to best practice in the industry is lost. To obtain this additional information frontier production function estimation techniques must be used.

The frontier production function approach to the measurement of total factor productivity (or technical efficiency) indicies, assumes that in any given sector we are likely to see both efficient and inefficient firms. The problem is to identify efficient enterprises and define the single "best practice" production function characterizing those efficient firms for the industry. In estimating the "best practice" frontier production function three issues have been cited in the literature as important: choice between alternative frontier model specifications, including deterministic models (linear programming and statistical deterministic) and stochastic models, the specification of the functional form of the production function (Cobb-Douglas, CES or translog), and selection of error term structure to be added to the production relation. In all these cases, given input levels, the ratio of the firm's observed output to the "best practice" frontier level of output is the resulting measure of relative technical inefficiency. Where the ratio of observed output to the frontier level of output is less than one, the firm is technical-inefficient. Each firm's technical inefficiency index is compared to determine relative efficiency. This approach allows the researcher to trace changes in output that could be obtained from shifting from one region of the frontier to another and to measure the magnitude of inefficiencies associated with operations inside the "best practice" frontier.

In a review of the various frontier estimation techniques, Corbo and de Melo concluded that different frontier approachesto measuring technical efficiencies yield broadly similar results. This conclusion is precisely true for firm level efficiency estimates within sectors. Hence, ease of calculation should be the guide for those choosing between techniques. In addition, it was shown that policy-induced price distortions in product and factor markets can cause biases in estimates of technical inefficiency when frontier techniques are employed.

Whichever method is used to calculate the production frontier the next task is to explain variations in efficiency relative to the frontier (and between firms) or along the frontier. Section III indicated that regression analysis is the most appropriate method for evaluating the sources of inefficiency, using a vector of firm and industry characteristics. Correlation techniques, which have been widely used in sources of inefficiency studies, have the disadvantage of not allowing one to isolate individual effects. In Section III.1, an alternative methodology was outlined to decompose the sources of technical inefficiency into components which make it possible to obtain both an improved insight into the causes of inefficiency as well as indications of potential policies to remedy these deficiencies.

The final section of the review dealt with efficiency measures in a dynamic setting. A methodology was introduced to decompose Total factor productivity growth into three components: technological progress, changes in technical efficiency, and output elasticity differences between the "best practice" production frontier and operations inside the frontier. Here technological progress is defined as changes in the best practice production frontier. A change in technical efficiency is defined as changes in the way a given technology is utilized. Firms can adopt new technology which shifts the best practice frontier, and/or firms can allocate resources to effect more efficient utilization of existing technology. These problems can be assessed in different firm size cohorts by estimating frontiers for each group over time. Lack of technological progress will be indicative of failures in investment planning and implementation, access to new technology and knowledge about new technology, and a policy environment which does not facilitate acquisition and adaptation of new foreign technology. Similarly, changes in technical efficiency across time periods and among individual firms indicates the success or failure of a number of important dimensions of economic policy.

FOOTNOTES

1. At least in the short-run, dynamic considerations could possibly outweight these static ratios.

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8. The formula for the return to self-financed capital would be:

$$r_o = \frac{VA - \left[r_b k(b) + W_h L(h)\right] - W_o L(o)}{K(o)}$$

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14. The unit isoquant represents the combinations of K and L that yield one unit of output.

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31. Ibid., Corbo and de Melo (1983).

32. Ibid., Corbo and de Melo, p. 30.

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43. Pack (1984) estimates the production frontier not by the programming technique outlined in this chapter, but by matching each enterprise in the LDC with a technologically similar "best practice" enterprise in a developed country; unit labor and capital requirements are calculated, as is relative total factor productivity. The whole exercise could be accomplished using the production frontier approach in section II.3.

44. Ibid., Nishimizu and Page (1982).

45. Ibid., Nishimizu and Page (1982) p. 247.