EFFICIENCY MEASUREMENT OF CONTAINER TERMINAL OPERATIONS: AN ANALYTICAL FRAMEWORK

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Abstract: As a major trade facilitator and a component in the total logistics chain, a container terminal should be managed and operated in a way which maximises efficiency. The efficient allocation and use of limited economic resources is a crucial factor that decision makers should take into account. With this context in mind, this paper aims to identify the characteristics of the container terminal industry in terms of performance measurement, critically review the previously used techniques for the performance measurement of container terminals, and finally justify the use of the frontier model as an analytical framework to determine the industry's efficiency and performance.

1. INTRODUCTION

As the business environment becomes more competitive and global than ever before, service industries, such as ports, are placing greater emphasis on customer satisfaction through providing quality services efficiently. As a major trade facilitator and a component in the total logistics chain, a port and/or terminal should be managed and operated in a way which maximises efficiency and performance given resources. In addition, the argument that a port and/or terminal needs to constantly seek to be competitive and efficient is further reinforced by the pace of advancement of modern communication technology and cargo handling equipment, which have great impact on its management and operations. This ever changing environment puts an addition financial burden on an industry which is already well known as being extremely capital intensive. As a consequence, the efficient allocation and use of limited economic resources is a crucial factor that decision makers should take into account.

Bearing the context in mind, this project aims to identify the characteristics of the port industry in terms of performance measurement, to critically review the previously used techniques for port performance measurement, and finally to justify the use of an econometric method known as the *frontier model* as an analytical tool to determine the industry's efficiency and performance.

2. THE CHARACTERISTICS OF PORT INDUSTRY

Historically, ports have acted as the interface between national or regional economies and the rest of the world (Haynes *et al.*, 1997). A port provides direct access to world markets and an excellent opportunity for access to the developing trade with a wide range of countries; in other words, a port can be regarded as a gateway for international trade or as a trade facilitator. Without an efficient port, the cost of living becomes higher, industrial development more difficult, and the export of domestic products unprofitable. Thus, the rate of economic progress is drastically curtailed.

In addition, the function of ports to their adjacent cities is substantial, offering a wide range of logistical and telecommunication activities, which are the main features of the 'third generation' ports (UNCTAD, 1992). Whatever these activities may be, however, maritime-related industries carry on their businesses in competitive markets. Under this circumstance, a port is considered as merely one link in a chain of transport, trading facilities and services involved in any given transaction. In this context, as Suykens (1989) argues, any improvement in the economic efficiency of a port will enhance economic welfare by increasing the producers' surplus for the originators of goods being exported and consumers' surplus at the final destination of the goods being imported.

When analysing the characteristics of a port wishing to serve the transportation needs of the future, Vogel (1994) has suggested that this really amounts to the container terminal of the future. His argument suggests that the container terminal will play a considerably more crucial role in international trade in the future. A recent report (Containerisation International, 1997) classifies the development of container ships into 'generations' as having characteristics typical of certain stages in container development and container shipbuilding.

Table 1. Physical Characteristics of Container Ships

Generations	Year	Maximum Capacity (TEU)
First Generation Container Ships	1964	1,000
Second Generation Container Ships	1972	1,500
Third Generation Container Ships	1980	3,000
Fourth Generation Container Ships	1984	4,500
Fifth Generation Container Ships	1995 ~	over 6,000

Source: Containerisation International (1997)

Table 1 shows that increases in size and cargo handling capacity are the main characteristics of each generation of container ship. Baird (1996) and Cullinane and Khanna (1997) discuss the on-going trend towards larger container ships and its impact on ports. Ports and terminals will not work properly and efficiently unless infrastructure is provided, as the container revolution increases momentum toward the year 2000 (Lloyd's List Maritime Asia, 1995). With regard to this situation, it might be worth noting the following quote:

> "In the highly competitive environment, ports have to make significant investments without any degree of assurance that traffic will increase. Their only guarantee is that unless there is a container handling facility, there will be little or no container traffic." (Haynes *et al.*, 1997, p. 99)

Based on the above discussion, we may draw a conclusion that a port, particularly a container port, is an industry which requires ever more capital as long as it is willing to carry on business and to remain competitive. In consequence, the efficiency of port management and operation, mainly cargo handling activities, becomes a pivotal issue.

3. A REVIEW OF PORT PERFORMANCE MEASUREMENT

Measures of port efficiency or performance use a certain form of output relative to input which quantifies various aspects of port operation. UNCTAD (1975) lists several benefits associated with a properly used set of port performance indicators. These include improving the utilisation of port resources, highlighting the cause of congestion as well as providing information for port planning and a justification for capital development. To measure, however, port performance and to compare it between ports is a very delicate matter (Suykens, 1983), as there are great differences in their geographical location and this sometimes influences their technical structures. The various sizes of ports, the variability of the ships calling at them and goods passing through them impose more difficulties in defining and measuring such performance. De Monie (1987, p. 1) points out the difficulties as follows:

- the sheer number of parameters involved;
- the lack of up-to-date, factual and reliable data, collected in an accepted manner and available for publication;
- the absence of generally agreed and acceptable definitions;
- the profound influence of local factors on the data obtained; and
- the divergent interpretations given by various interests to identical results.

In addition to the awkwardness caused by factors such as these, another thing which greatly complicates measurement is the fact that the operational performance of a port or terminal is normally judged by measurements that are heavily dependent on factors over which the port or terminal has limited or no control (Dowd and Leschine, 1990). The limiting factors are either physical (e.g. geographical location of the port and the type of vessels visiting the port) or institutional factors (e.g. union work rules, customs regulations, and requirements imposed on the port operator by carriers) or a combination of both.

Traditionally, the performance of ports has been evaluated either by calculating cargo-handling productivity (e.g. Bendall and Stent, 1987) or by measuring a single factor productivity (e.g. labour as in the case of De Monie, 1987), or by comparing its actual throughput (i.e. tonnage or number of containers handled) with its optimum throughput for a specific period of time (e.g. Talley, 1988). The crucial aspect in the latter approach is how to determine the optimum throughput of a port, since port performance is a relative measure which depends on this measured optimum throughput. In a case where reliable estimates of economic optimum throughput are not available, Talley (1988; 1994) suggests that performance indicators related to the port's economic objective may be used to evaluate its overall performance. In a private port, its economic objective may be to maximise profits while, in a public port, its objective may be to maximise throughput subject to a zero profit (or zero deficit) constraint. Such an approach, however, suffers from another problem, how should these indicators be selected?

In an effort to properly evaluate the efficiency or performance of a port, several methods have been suggested, such as estimation of a port cost function (De Neufville and Tsunokawa, 1981) or the estimation of the total factor productivity of a port (Kim and Sachish, 1986). Tongzon (1995) attempts to establish a model of port performance and efficiency and to quantify the relative contribution of each variable to overall performance and efficiency using multiple regression. In so doing, it is assumed that ports are throughput maximisers and that the definition of port performance is measured in terms of the number of containers moved through a port.

As noted by Braeutigam *et al.* (1984), however, various types of ports are of different size and face a variety of traffic mix. As such, the use of cross-sectional, time-series or even panel data may fail to show basic differences amongst ports, thus leading to a misjudgement of each port's performance. It is, therefore, crucial to estimate econometrically the structure of production in ports at the single port or terminal level using appropriate data such as the panel data for a terminal (Kim and Sachish, 1986).

In respect to attempts to derive a port production function, Chang (1978) focused on general cargo-handling as a measurement of port performance and assumed that port operations follow the conventional Cobb-Douglas case as expressed by:

$$\mathrm{Y} = AK^{\alpha}L^{\beta}e^{\gamma(T/L)} \tag{1}$$

. . . where Y is annual gross earnings (in real term), K is the real value of net assets in the port, L is the number of labourers per year and the average number of employees per month each year, and $e^{\gamma(T/L)}$ a proxy for technological improvement, in which (T/L) shows the tonnage per unit of labour. Chang (1978) argued that, for the estimation of a production function such as (1), the output of a port should be measured in terms of either total tonnage handled at the port or its gross earnings. This was to be preferred to port services, since the production function of an organisation involves its internal operation. Bendall and Stent (1987) improve the model (1) to aid policy makers in assessing the merits of different ship types.

4. ECONOMIC EFFICIENCY AND THE FRONTIER MODEL

4.1 Allocative and Productive Efficiency

The matter of economic efficiency has been of interest since Adam Smith's pin factory. In economic theory, costs can exceed their minimum feasible level for one of two reasons (Barrow and Wagstaff, 1989). One is that inputs are being used in the wrong proportions, given their prices and marginal productivity. This phenomenon is known as *allocative inefficiency*. The other reason is that there is a failure to produce the maximum amount of output from a set of given inputs. This is known as *productive inefficiency*. Both sources of inefficiency can exist simultaneously or in isolation. These sources of inefficiency can be easily explained by using the concept of a production function.

Suppose that a firm's frontier production function, as depicted in Figure 1, is $\mathrm{Y} = f(x_1, x_2)$, where two inputs (x_1 and x_2) are used to produce one output (Y) and that the function is characterised by constant returns to scale. The isoquants $\mathrm{Y_A}$ and $\mathrm{Y_B}$ indicate all possible combinations of x_1 and x_2 which give rise to the same level of output.

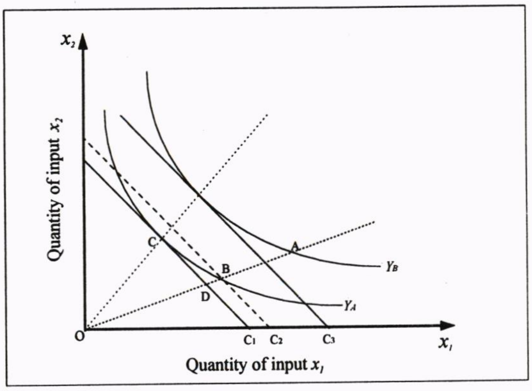

Figure 1. Frontier Production Function

Assume that the firm's efficiency is observed at point A, rather than C. This position is neither allocatively nor productively efficient. Its level of productive efficiency is defined as the ratio of OB/OA. Therefore, *productive inefficiency* is defined as 1-(OB/OA) and can be interpreted as the proportion by which the cost of producing the level of output could be reduced given the assumption that the input ratio (x_1/x_2) is held constant. Under the assumption of constant returns to scale, productive inefficiency can also be interpreted as the proportion by which output could be increased by becoming 100 % productively efficient. The level of allocative efficiency is measured as OD/OB (or C_1/C_2). Thus *allocative inefficiency* is defined as 1-(OD/OB) and measures the proportional increase in costs due to allocative inefficiency.

4.2 The Frontier Models

Over the last decade a number of methods for measuring efficiency have been proposed, all of which have in common the concept of the frontier: efficient units are those operating on the cost or production frontier, while inefficient ones operate either below the frontier (in the case of the production frontier) or above the frontier (in the case of the cost frontier).

There is one difference to be noted concerning the interpretation of the term 'frontier'. Some methods aim to uncover the *absolute* frontier, indicating what could be achieved if the available technology were used to full advantage; others aim to uncover the *best-practice* frontier, reflecting the achievements of the firm or industry in the sample (Barrow and Wagstaff, 1989). As Forsund *et al.* (1980) noted, however, the distinction is unlikely to be of much significance in practice, since the two different concepts of the frontier converge as sample size tends to infinity.

Bauer (1990, p. 39) pointed out the following reasons why the use of frontier models is becoming increasingly widespread:

- the notion of a frontier is consistent with the underlying economic theory of optimising behaviour;
- deviations from a frontier have a natural interpretation as a measure of the efficiency with which economic units pursue their technical or behavioural objectives; and

- information about the structure of the frontier and about the relative efficiency of economic units has many policy applications.

The literature on frontier production function models begins with Farrell (1957), who suggested a useful framework for analysing economic efficiency in terms of realised deviations from an idealised frontier isoquant. These and other frontier models are motivated in part by an interest in the structure of efficient production technology, in part by an interest in the divergence between observed and frontier operation and also in economic efficiency.

A distinction exists between the methods employed to derive the specification of the frontier model: either *statistical* or *non-statistical* methods may be used. The former technique makes assumptions about the stochastic properties of the data, while the latter does not. Another difference concerns whether the chosen method is *parametric* or *non-parametric*. While the former imposes a particular functional form, the latter approach does not. Again, the parametric approach can be divided into deterministic and stochastic frontier models. While the non-parametric approach revolves around mathematical (or linear) programming techniques known as Data Envelopment Analysis (Mansson, 1996), the parametric approach employs econometric techniques where efficiency is measured relative to a frontier production function which is statistically estimated.

Econometric approaches are founded on the concept that a process can be adequately described by examining its inputs and its outputs. It is not necessary to know anything about the technologies involved in the production process; all that is needed is a set of reliable observations of what goes in and what comes out (Heathfield and Wibe, 1987). The parameter values are then statistically inferred from these observations. Thus, this approach involves the specification of a parametric representation of technology which itself can be divided into two different models; either *deterministic* or *stochastic* frontiers may be specified according to whether or not certain assumptions are made concerning the underlying data.

4.2.1 The Deterministic Frontier Model

Aigner and Chu (1968) suggest a homogeneous Cobb-Douglas frontier production function which requires that all observations are on or beneath the frontier. Their model can be expressed as:

$$Y = f(X; \beta) - u, \tag{2}$$

. . . where Y denotes the output, X a vector of inputs, β the input coefficients and u (≥ 0) is a one-sided error term which ensures that $Y \leq f(X; \beta)$. Although Aigner and Chu (1968) did not do so, the productive efficiency of each observation can be computed directly from the vector of residuals, since u represents 'productive inefficiency'. It is labelled as 'deterministic' because, according to Greene (1993), the stochastic component of the model is contained entirely in the inefficiency term, u.

The main advantage of this approach as compared to the programming approach is its ability to characterise frontier technology in a simple mathematical form. As pointed out in both Forsund *et al.* (1980) and in Bauer (1990), however, the disadvantages of the frontier model represented in equation (2) are the mathematical form may be too simple, the model imposes structure on the frontier that may not be guaranteed, the approach often imposes a limitation on the number of possible efficient observations, the estimated frontier is supported by a subset of the data and is thus extremely sensitive to outliers, and the estimated results have no statistical properties; since no statistical assumptions are made about the disturbance term u in the model represented in (2), inferences cannot be reliably obtained from the results.

Since no efficiency differences between economic units are assumed to be generated by an explicit efficiency distribution, as Aigner and Chu (1968) admit, the estimation potential of the deterministic model (2) is reduced to some extent by this lack of available statistical procedures for the drawing of inferences. In an attempt to overcome this major drawback, namely no statistical basis, Afriat (1972) amended the frontier model to facilitate statistical analysis by making some assumptions about it. The equation in (2) can be rewritten as:

$$Y = f(X; \beta) \exp(-u), \tag{3}$$

or

$$\ln Y = \ln f(X; \beta) - u \tag{4}$$

. . . where $u \geq 0$ (and thus $0 \leq \exp(-u) \leq 1$), and where $\ln f(X; \beta)$ is linear in the Cobb-Douglas case exhibited in (2). The question that has to be asked is what to assume about X and u. One possible answer that has been most frequently used is to assume that observations on u are identically and independently distributed (*iid*), and that X is exogenous and thus independent of u. Any number of distributions (e.g. normal, half-normal and exponential distributions) for u or $\exp(-u)$ could be specified.

The early parametric frontier models are deterministic in the sense that all economic units share a common fixed class of frontier. This is, of course, unreasonable and ignores the real possibility that the observed performance of the economic unit may be affected by exogenous (i.e. random shock) as well as endogenous (i.e. inefficiency) factors. This argument is reinforced if one considers also the statistical noise that every empirical relationship contains. In addition to random shocks, statistical noise may be interpreted as having two sources: measurement error and misspecification of functional form. Both sources are as relevant for the production function as for any other model. To allocate all these influences, whether favourable and unfavourable or whether under or beyond the control of the economic unit, into a single disturbance term and to label the mixture as inefficiency is clearly a doubtful and inexact generalisation. In fact, to distinguish statistical noise from inefficiency, and to assume that the noise is one-sided, therefore, are both questionable assumptions to make. As a result, the parametric approach is highly sensitive to extreme outliers, thus causing an over- or under-estimation of the true extent of inefficiency. Rather than overcoming these problems through the extension and further development of deterministic frontiers, an alternative model based on the concept of a stochastic frontier model can be utilised.

4.2.2 The Stochastic Frontier Model

The stochastic frontier model (also often named the 'composed disturbance model') is motivated by the idea that deviations from the production frontier might not be entirely under the control of the economic unit being studied (Greene, 1993). Both Aigner *et al.* (1977) and Meeusen and van den Broeck (1977) independently constructed a more reasonable error structure than a purely one-sided one. They considered a linear model for the frontier production function as follows:

$$Y_{it} = f(X_{it}; \beta) \exp(\varepsilon_{it}), \qquad i = 1, 2, \ldots, N; t = 1, 2, \ldots, T \tag{5}$$

. . . where i indexes firms and t time periods. Their disturbance term ε_{it} is defined as the following:

$$\varepsilon_{it} = v_{it} - u_{it} \tag{6}$$

The component v_{it} represents a *symmetric disturbance term* permitting random variation of the production function across economic units due not only to the effects of measurement and specification error, but also to those of exogenous shock beyond the control of the economic unit (e.g. luck, weather conditions, geography or machine performance). The other component u_{it} (≥ 0) is a *one-sided disturbance term* and represents 'productive inefficiency' relative to the stochastic production function. The non-negative disturbance u_{it} reflects the fact that output lies on or below its frontier. The deviation of an observation from the deterministic kernel of the above stochastic production function arises from two sources: (i) symmetric random variation of the deterministic kernel $f(X_{it}; \beta)$ across observations captured by the component v_{it} and (ii) asymmetric variation or productive inefficiency captured by the component u_{it}. The term u_{it} measures productive inefficiency in the sense that it measures the shortfall of output Y_{it} from that implied by its maximum frontier given by $f(X_{it}; \beta) \exp(v_{it})$.

The measure of an economic unit's efficiency should be defined, therefore, by:

$$\frac{Y_{it}}{f(X_{it}; \beta) \exp(v_{it})} \tag{7}$$

. . . relative to the stochastic frontier $f(X; \beta) \exp(v)$. Thus, the frontier $f(X; \beta) \exp(v)$ is stochastic since v consists of random factors which are beyond the control of the production unit.

Nevertheless, any estimate of a firm's efficiency level is not consistent, as it contains statistical noise as well as productive inefficiency. In addition, stochastic frontier models suffer from two other difficulties. One is the requirement of specific assumptions about the distributions underlying productive inefficiency (e.g. half-normal and exponential) and statistical noise (e.g. normal). The other is the required assumption that the regressors (the input variables X) and productive inefficiency are independent. This may well be an unrealistic assumption since, if a firm knows its level of inefficiency, this should affect its input choices.

Econometric approaches, however, have a strong policy orientation, especially in the assessment of alternative industrial organisations and in the evaluation of efficiency in government and other public agencies. Mathematical programming approaches, on the other hand, have a managerial decision-making orientation (Aigner and Schmidt, 1980; Fare *et al.*, 1994; Lovell, 1995).

In addition, several studies (e.g. Gong and Sickles, 1992; Oum and Waters, 1996) have compared the performance of alternative methods for measuring efficiency: the econometric method (in particular, the stochastic frontier model) and the mathematical programming method. The results show that the econometric approach generally produces better estimates than the latter approach, especially for measuring firm-specific efficiency when panel data are available. Greene (1993) notes that the main advantage of the econometric method lies in its ability to shift the harmful effect of measurement error away from estimates of efficiency.

4.2.3 Panel Data in the Frontier Model

A further development in the modelling of frontiers lies with the use of estimation techniques which involve panel data. Initially, the stochastic frontier model (5) was developed for cross-sectional data. According to Intriligator *et al.* (1996), panel data are a special type of pooled cross-section and/or time-series data in which the same individual units of observation are sampled over time and are generally microdata pertaining to individual economic agents, such as families and firms. Baltagi (1995) lists several benefits from using panel data, one of which is the capability to identify and measure effects that are simply not detectable in pure cross-sectional or pure time-series data.

In addition, a number of attractive features of panel data are suggested by Hausman and Taylor (1981) and Blundell (1996). Among them are (i) that panel data are able to control individual effects which may be correlated with other variables included in the specification of an economic relationship, thus making analysis on single cross-sections difficult, and (ii) that panel data allow an analyst to exploit the large variation in the circumstances of different individuals in any cross-section while still capturing temporal effects in behaviour.

With respect to the frontier production function, consistent estimates of the productive efficiency of an economic unit can be obtained as the number of time periods tends to infinity. This is true because adding more observations on the same unit yields information not attainable by adding more units. Secondly, unlike the techniques for cross-sectional analysis which draw evidence of inefficiency from skewness (e.g. Waldman, 1982), the technique of panel data analysis draws evidence of inefficiency in constancy over time. As a consequence, strong distributional assumptions are not necessary when panel data are available. Finally, the parameters and the economic unit's level of efficiency can be estimated without assuming that the input variables are uncorrelated with productive inefficiency. Therefore, as Schmidt and Sickles (1984) note, a variety of different estimates will be considered, depending on what one is willing to assume about the distribution of productive inefficiency and its potential correlation with the regressors.

The aforementioned models involved the estimation of the parameters of the stochastic frontier production function and the mean productive inefficiency for firms in the industry. Initially, it was claimed that productive efficiencies for individual firms could not be estimated and predicted. In an effort to explore this unsolved problem with the previous models along with the benefits from the aforementioned advantages of panel data, Pitt and Lee (1981) were the first to develop techniques using panel data to estimate the frontier production function. Their approach failed, however, to utilise the qualitative advantages of panel data and required strong assumptions, exactly as was the case for models using the cross-sectional data.

Jondrow *et al.* (1982) presented two estimators (i.e. for half-normal and exponential cases) for the firm-specific effect for an individual firm under the assumption that the parameters of the frontier production function were known and cross-sectional data were available for given sample firms. Schmidt and Sickles (1984) suggested three different estimators for individual firm effects and productive efficiencies for panel data. A major breakthrough in the area of panel data models was achieved by Battese and Coelli (1988), who presented a generalisation of the results of Jondrow *et al.* (1982) on the assumption of a more general distribution for firm effects to be applied to the stochastic frontier model. Ferrantino and Ferrier (1995) adopted the methods developed by Pitt and Lee (1981) and Battese and Coelli (1988) to derive firm-specific efficiency estimates based on available panel data for Indian vacuum-pan sugar producers.

Suppose that the frontier production function is of the following form:

$$\mathrm{Y}_{it} = f(\mathrm{X}_{it}; \beta) \exp(v_{it} - u_i), \qquad i = 1, 2, \ldots, \mathrm{N}; t = 1, 2, \ldots, \mathrm{T} \tag{8}$$

. . . where Y_{it} denotes the appropriate form of output for the ith firm at time t, X_{it} is a vector of inputs associated with the ith firm at time t and β is a vector of input coefficients for the associated independent variable in the production function. The main difference between models (5) and (8) is the absence of the subscript t associated with u in the latter, thus u captures firm-specific time invariant variables omitted from the previous production function.

The symmetric terms v_{it} are assumed to be identically and independently normally distributed with mean zero and variance σ_v^2, i.e., $v_{it} \sim N(0, \sigma_v^2)$. The one-sided terms u_i ($\geq$ 0) are assumed to be identically and independently distributed non-negative random variables, which captures a *firm* effect but no *time* effect (Schmidt and Sickles, 1984). In addition, the error terms v_{it} and u_i are assumed to be independently distributed of the input variables as well as of one another.

The most frequently defined distribution for the u_i is the half-normal (often termed the absolute normal distribution), i.e., $u_i \sim |N(0, \sigma_u^2)|$. Other distributional assumptions for the terms u_i have been proposed by several researchers. For example, the exponential (Aigner *et al.*, 1977), the truncated normal (Stevenson, 1980) and the gamma (Greene, 1980).

As far as the productive efficiency of a firm is concerned, Battese and Coelli (1988) define it as the ratio of the firm's mean production (given its realised firm-specific effect) to the corresponding mean production with the firm effect being equivalent to zero. The productive efficiency of the ith firm (PE_i) is defined, therefore, as:

$$\mathrm{PE}_i = \frac{E(\mathrm{Y}_{it}^* | u_i, \mathrm{X}_{it})}{E(\mathrm{Y}_{it}^* | u_i = 0, \mathrm{X}_{it})} \tag{9}$$

. . . where Y_{it}^* represents the output of production for the ith firm at time t, and the value of the PE_i lies between zero and one ($0 \leq \mathrm{PE}_i \leq 1$). If a firm's productive efficiency is calculated as 0.65, for example, then this implies that, on average, the firm realises 65 % of the production possible for a fully efficient firm having comparable input values. From the perspective of efficiency measurement, the definition contained in equation (9) has a thread of connection with that of equation (7).

If the model (8) is transformed to a logarithm of the production function, such as:

$$\ln Y_{it} = \ln f(X_{it}; \beta) + v_{it} - u_i \tag{10}$$

. . . then the measure of productive efficiency for the *i*th firm is defined by:

$$PE_i = \exp(-u_i) \tag{11}$$

The measure shown in equation (11) does not depend on the level of the input variables for the firm, while the definition provided by equation (9) for calculating the productive efficiency of a firm clearly shows that its estimation depends significantly on inferences concerning the distribution function of the unobservable firm effect u_i, given the sample observations.

In the early stages of its use, one problem with the stochastic frontier model was that the model provides estimates of productive efficiency only in terms of a sample mean, rather than of each observation. This is because v and u are unobservable. In order to solve this drawback, Jondrow *et al.* (1982) described a method for extracting estimates of productive efficiency for each observation in the sample, by decomposing the frontier residual ($v_{it} - u_i$) into its components: statistical noise (v_{it}) and productive inefficiency (u_i). This decomposition can be conducted by finding the expected value of u_i under the conditional distribution of u_i given ($v_{it} - u_i$).

This method provides unbiased, but inconsistent, estimation of u_i (Greene, 1993). Battese and Coelli (1988) refined the method of Jondrow *et al.* (1982) for the case of panel data. The elaborated technique by Battese and Coelli (1988) and Battese *et al.* (1989) was, however, for the case where productive efficiency is time-invariant. With regard to this time-invariant model for firm-level efficiency, Schmidt (1985, p. 313) states the following:

> "Unchanging inefficiency over time is not a particularly attractive assumption. . . . . . . An important line of future research, in my opinion, is to allow inefficiency to change over time"

With the assumption that productive efficiency does vary over time, an alternative approach has been adopted by econometricians such as Cornwell *et al.* (1990) and Kumbhakar (1990). None of these studies succeed, however, in completely separating inefficiency from individual firm effects (Kumbhakar and Hjalmarsson, 1993) and, in any case, the proposed method is too complicated for empirical application (Ferrantino and Ferrier, 1995).

In summary, in spite of the fact that the panel data model enables a researcher to relax certain assumptions, since the techniques of panel data analysis are focused on cross-sectional variation, this approach requires the additional assumption that individual firm inefficiency is invariant with time. At the same time, the problem remains that a restrictive functional form for technology is imposed on the model. Finally, the following remarks of Bauer (1990, p. 41) are worthy of note:

> "Stronger assumptions generate stronger results, but they strain one's conscience more. . . . . The appropriate structure to impose can only be determined by a careful consideration of the data and the characteristics of the industry under study."

5. THE FRONTIER MODEL AS A NEW PORT PERFORMANCE EVALUATOR

From the discussion so far, we can apply the frontier model to the port industry so as to measure the relative efficiency of its operations. The data used in this model can be taken from the annual, quarterly or monthly management reports and financial accounts which have either been made available or published by port operating companies. The panel observations on output and inputs for each company can be established. What follows is some practical considerations in applying the frontier model methodology to the container terminal sector.

5.1 Model Specification and Assumptions

The estimation of relative port operator efficiency is conducted by assuming the appropriateness of the Cobb-Douglas case. The frontier model specified for the terminal operating sector is, therefore, defined by:

$$\ln Y_{it} = \ln f(L_{it}, K_{it}; \beta) + v_{it} - u_{it}, \qquad i = 1, 2, \ldots, N;\ t = 1, 2, \ldots, T \tag{12}$$

where Y_{it} represents the output of the ith port/terminal operator and the tth time, L_{it} and K_{it} denote labour and capital inputs respectively, associated with the ith port/terminal operator in the tth time and β is a vector of input coefficients for the associated independent variables in the model. Based on the model (12), the productive efficiency of each terminal operating company can be measured using equation (9) or (11).

For the purpose of the empirical analysis, some assumptions also have to be made. The overall objective of port/terminal operators is assumed to be the maximisation of their profits stemming from operational activities. In other words, a port/terminal operating company is regarded as a profit-maximiser. The port/terminal operators are also assumed to be price takers in their input markets. Hence, input prices may be treated as exogenous. Another assumption necessary for operationalising the models given in (12) is that it is a single-output production function. This is justified on the basis that the main operational function of container terminals and the main issue of policy interest is *container handling*. Thus, earnings from sources such as the sales of terminal property are not classified as output and do not effect the production function frontier.

5.2 Description of the Variables in the Model

Dowd and Leschine (1990) argue that the productivity of a container terminal depends on the efficient use of labour, land and equipment. It seems logical, therefore, to take labour and capital (including land, buildings and equipment) as the input variables for a terminal production function. An analysis of an expenditure structure of a port over time to a conventional division among inputs is shown in Figure 2. As a proxy for the capital input variable, the combined values of buildings and equipment (mainly cargo-handling equipment) accounts for 42% of total expenditure. Thus, the labour and capital costs of a port or terminal together comprise 95% of the total cost structure of port or terminal operations. It seems reasonable enough to assume that this can be taken as sufficient to describe the whole cost account.

Labour input can be defined as an aggregate of the number of employees in a terminal operation. This will likely relate to two complementary, but fundamentally different groups of labourers: those hired directly by the terminal company and the stevedores employed by stevedoring companies who work on a sub-contract basis. With regard to the level of skill of labourers, the total wage bill (payments made for labour) which is quoted in value terms rather than in physical terms (the number of employees) may, to some extent, be a preferable input variable. The input *Capital* variable can be taken as the aggregated value of fixed capital assets including land, buildings and equipment.

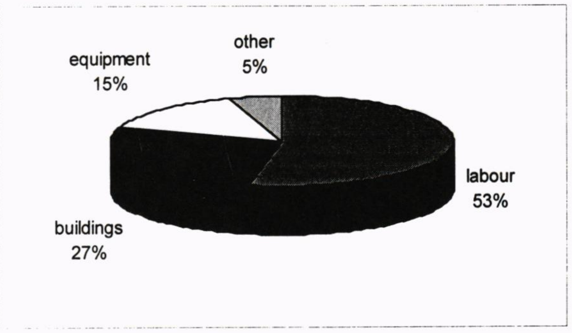

Figure 2. Port/Terminal Expenditure Structure

As far as the *output* of a container terminal is concerned, there are two alternatives: a proxy either in value terms or in physical units. Financial output may be measured in terms of 'turnover', while physical units such as 'TEU throughput' may also be used since the unit of container TEU is regarded as a homogeneous product which, in practice, is a very realistic assumption to make. The output of a terminal can, therefore, be measured in TEU throughput over a given time period and, in the future, it seems likely that this will increasingly be the case. Finally, where relevant, the data for all variables collected may need to be deflated by appropriate price indices to incorporate real values in the analysing and ensuing model estimation.

6. CONCLUDING REMARKS

This paper has attempted to suggest the frontier model as an analytical framework for performance or efficiency measurement of ports, particularly container ports, which play a crucial role in international trade. A port, as a trade facilitator, should be operated in an efficient way so as to improve the competitiveness of a country where the port is located. Several studies have endeavoured to measure the performance or efficiency of the port using a variety of methods. Those methods, however, failed to provide a systematic framework applicable to the port industry.

The proposed analytical technique as a means of port or terminal efficiency measurement, however, has great potential and may provide governments, port authorities and other interests with information on and guidelines for the implementation of port policies and organisational reforms. Moreover, there has been little research involving the application of the chosen methodology to the port or container terminal sectors, and the potential for extending this method to other transport industries is enormous.

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