CHAPTER 3

OVERVIEW OF PRODUCTIVITY AND EFFICIENCY MEASUREMENT

This section discusses the concept of productivity and the theoretical and empirical development in measuring productive efficiency in telecommunications industry.

3.1 DEFINITION

The issues surrounding the definition and measurement of productivity have been the topic of research for a variety of disciplines, which includes accountancy, engineering and economics. Productivity is generally defined as the quality or degree of producing a set of desired effects. It is how inputs are transformed into useful output within the production process. In other words, it is the ratio of output to input for a specific production situation. Rising productivity implies either more output is produced with the same amount of inputs, or that less input are required to produce the same level of output. Thus, the concept of productivity is linked closely with the issue of efficiency.

From the economics perspective, there are several sources of efficiency which contribute to higher level of productivity. Farrel (1957) for example, categorizes efficiency into two components: technical efficiency and allocative efficiency. Fare et al. (1985) provide another component, structural efficiency, along with the other two components.

Another source of productivity growth that is regularly reported in productive efficiency studies is scale efficiency. All these productive efficiency components are defined as follows:

- Technical efficiency: firm's ability to obtain the maximum possible output from a given set of inputs
- Allocative efficiency: firm's ability to maximize its profits by minimizing the cost of production with market prices information.
- Structural efficiency: measures how the industry keeps up with the performance of its own most efficient firms.
- Scale efficiency: firm's ability to produce output with a minimum average cost. This corresponds to the long run equilibrium where the firms exhibit constant return to scale and zero profit.

Another concept that is also related to productivity is technology. Technology is generally defined as a set of specification of inputs and operations, which are to be performed to create output of a given quality. A change in technology reflects greater efficiency and higher productivity. Early adopters of new technology will appear to be technically more efficient than late adopters. Moreover, firms' level of efficiency also depends on the vintage of its capital. Firms with recent vintage will tend to appear technically more efficient than the firms with older vintage.

In relation to this, Fare et al. (1994a) for example, categorized productivity growth into two mutually exclusive components which are efficiency change and technical change over time. These two components identify the contributions of catching up efficiency and innovation in technology to the productivity growth. Nevertheless, there are also small number of writers who consider productivity growth and technical progress as synonymous.

3.2 DEVELOPMENT IN THE AREA OF PRODUCTIVITY AND EFFICIENCY MEASUREMENT

Modern writing on producers' theory assumes that producers are always efficient by optimizing their behavior. Producers are also assumed to allocate resources efficiently so as to minimize their overall costs. However, for a variety of reasons not all producers succeed in solving both type of optimization problem in all circumstances. Hence, in the past few decades, a growing number of writers have begun to turn their attention to the possibility of inefficiency in production with emphasis placed on measurement of degree of inefficiency and productivity.

Among the earliest approach to productivity measurement was the one based upon ratios of a measure or index of aggregate output divided by the observed quantity of single input, typically labor. These productivity ratios proposed by Knight (1933) were usually normalized to some based year, resulting in a productivity index over time, and were used to measure aggregate productivity, that is, productivity for the entire economy. This index-number approach based upon the use of single or partial factor productivity measures have remained as the single most widely discussed index in literature due to the advantage of computational simplicity and feasibility. Nevertheless, this method and measurement has made it difficult to identify the causal factors accounting for observed productivity growth. For example, the substitution of capital for labor, the introduction of more labor efficient vintages of capital, the realization of economies of scale, and the employment of better-trained manpower all show up in the form of increases over time in an index of output per man-hour.

Following this, a more comprehensive index-number approach was introduced based on total factor productivity (TFP) measures. Essentially, TFP indexes consist of a ratio of two separate indexes, one for output and the second representing total input. The output index or measure may be either a simple unweighted measure of relatively homogeneous output, or a weighted measure of heterogeneous joint outputs. At the firm level, the input measure should include all inputs used in the production process, e.g., labor, capital, and materials, and must include all phases of the production process, e.g., transmission and distribution in the case of telecommunication. This TFP measures are a clear improvement over single-factor measures in which changes in the quantity and quality of all inputs can be accounted for and they have been used extensively by both Denison (1962,1967, 1971) and Kendrick (1961, 1973) in their work at aggregate level. However, the difficulties of disentangling technical change from the effects of scale economies and input substitution remain.

An alternative approach to measuring productivity involves the explicit specification of a production function and the direct linkage of productivity growth to key characteristics or parameters of this function. An additional benefit of this approach is that its econometric implementation yields parametric estimates of the production technology in the process of measuring productivity advancement. The pioneering paper in developing this approach is that of Solow (1957), who demonstrated that the rate of productivity growth could be identified with the rate of Hicks-neutral technical change, assuming constant returns to scale and competitive markets. This result clearly established the correspondence between the characteristics of a neoclassical technology and improvements in total factor productivity, at least under the maintained assumptions of a competitive equilibrium and Hicks-neutral technical change.

A more recent development within the production function or neoclassical tradition, and one that has both theoretical and economic implications for the measurement of productivity, is the cost model based upon duality theory and the early work of Shephard (1970), and MacFadden (1978). The cost function represents a unique relationship between minimal costs and given output and input prices, that is, it represents the relationship between total cost and output for a cost-minimization firm facing competitive input markets. The most basic result of duality theory is that production and cost functions are dual to each other in that the cost function is equivalent and equally fundamental specification of the underlying production technology to that of the production function, under the assumption of cost minimization. In addition, the cost function can be used to relate such technological characteristics as scale economies, input substitution, and technical change to observed changes in TFP. Thus, the cost-function model represents a powerful and flexible econometric tool for measuring TFP, especially at the firm level and where the required assumptions of exogenous output and input prices and cost-minimizing behavior are tenable.

Parallel to these theoretical developments in duality theory has been the related work in the development of more general and flexible specifications of a neoclassical technology- such as translog, quadratic, and generalized Leontief models- which require fewer restrictions than the older Cobb-Douglas and constant elasticity of substitution (CES) specifications. Given these developments, it is not surprising that recent productivity studies have been largely centered upon the use of flexible specifications of a neoclassical cost function.

Noticing that the area of index-number theory is related to the problem of output and input aggregation, Diewert (1976, 1979) and others in the area of "exact" or "superlative" index numbers have shown that there is a unique correspondence between the type of index used to aggregate over outputs and inputs and the structure of the underlying technology. For example, the Laspeyres indexing procedure, used in many of the earlier productivity studies, has shown to be exact for, or imply, a linear production function in which all inputs are perfect substitutes in the production process. Similarly, the Tornqvist index, a discrete approximation to the more general Divisia index, implies a homogenous translog production function. Thus, any given index number implies a particular structure for the underlying production technology and for that, considerable care must be taken in the selection of the appropriate aggregation or index procedure. Unfortunately, it is also true that the more complex types of index numbers are required under the assumption of more flexible, and hence more general, specifications of the technology. The basic importance of this work lies in the linkage of the two approaches to TFP measurement, index number and neoclassical production and cost function, in that the problem of selecting an appropriate production function and a suitable index number have shown to be dual to each other.

Another recent and modern development in the area of productivity and efficiency measurement is the use of frontier analysis. The development of frontier analysis originated from the theoretical literature on productive efficiency in the 1950's with the work of Koopmans (1951), Debreu (1951), and Shephard (1953). According to Koopmans (1951), a producer is technically efficient if, and only if, it is impossible to produce more of any output without producing less of some other output or using more of some input. Debreu and Shephard introduced distance functions as a way of modeling multiple-output technology as a way of measuring the radial distance of a producer from a frontier, in either output-oriented or input-oriented directions. The association of distance functions with technical efficiency measures was pivotal in the development of modern productivity and efficiency measurement literature.

Farrel (1957) was the first to measure productive efficiency empirically. Drawing inspiration from Koopmans and Debreu, Farrel showed how to define cost efficiency, and how to decompose cost efficiency into its technical and allocative components. He also provided an empirical application to U.S. agriculture with the use of linear programming techniques (non-parametric approach) which later influenced the development of data envelopment analysis (DEA) by Charnes, Cooper, and Rhodes (1978).

Another approach to frontier analysis is by using stochastic frontier analysis. This approach was independently proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and Van Den Broeck (1977). The original specification involved a production function specified for cross-sectional data which had an error term for two components, one to account for random effects and another to account for technical efficiency. The specification has also been altered and extended in a number of ways. These extensions include the consideration of panel data and time-varying technical efficiencies; the extension of the methodology to cost functions and also to the estimation of systems of equations; and so on[5]. This model has been used in a vast number of empirical applications over the past two decades.

With the development of the distance function, Caves, Christensen and Diewert (1982) introduced the Malmquist productivity index. Originating from the Malmquist quantity index, the output distance function was then promoted as a natural generalization of the single output measure of efficiency given by the ratio of actual to potential output. These efficiency indexes take the technology as given and aggregate across output or input quantities to obtain a scalar measure of the shortfall from the efficient production frontier.

[5] Comprehensive reviews of this literature are available in Schmidt (1986), Bauer (1990), Greene (1993) and Kumbhakar and Lovell (2000).

Although the paper was extremely influential and widely cited, the Malmquist productivity index itself was rarely computed, until Fare, Grosskopf, Lindgren and Ross (1989) showed how it could be calculated using a non-parametric linear programming method. To date, the Malmquist productivity indexes have been used in a variety of studies. These studies include agriculture, airlines, banking, electric utilities, telecommunications, insurance companies and public sectors as well as between countries comparisons of productivity.

3.3 RELEVENT LITERATURE ON TELECOMMUNICATIONS SECTOR

The literature on efficiency and productivity of telecommunications industry is extensive. Earlier papers have focused more on the cost and production structure of firms by examining the existence of scale economies and the indices of productive, technical and allocative efficiency. Early literature on this topic was written by Fuss and Waverman (1977), Denny, Everson, Fuss and Waverman (1979) and Denny, Fuss and Waverman (1981) in which studied the Canadian Telecommunications sector. Among these, Denny, Fuss and Waverman (1981) provide the most detailed examination of input and output growth for *Bell Canada* for the period of 1952 to 1976. The authors find substantial productivity growth in *Bell Canada* over these periods. Specifically, aggregate real inputs grew at an average annual rate of 8.5 percent from 1952 to 1957, and then declined to an average rate of less than 5 percent from 1958 to 1976. On the other hand, aggregate real output showed no associated decline in growth indicating impressive productivity growth for *Bell Canada*. They also found that scale economies contributed about three-fifth of

TFP growth, whereas non-marginal cost pricing and technical change contributed about one-fifth each.

Similar method was adopted by Nadiri and Schankerman (1981) to measure the rate of TFP growth for the *US Bell System* which covers the period of 1947 to 1976. However, they enlarged their analysis by introducing research and development (R&D) as new input variable. Their decomposition of TFP growth indicates that scale economies account for between 60 and 70 percent over the entire post-world war II period, but the relative importance of scale economies as a source of TFP growth has declined over time. They suggest that this decline however, does not reflect the exhaustion of scale economies. Instead, it is due to the fact that total factor input grew at a slower rate relative to TFP during the later periods.

Solimene (1994) on the other hand, studied the TFP growth for Italian telecommunications industry. The study refers to the period of 1975 to 1991 and uses the Divisia index with the discrete approximation given by Tornqvist index. Comparative analysis was made between TFP and labor productivity growth for two telecommunication firms *(Sip and Italcable)* and the result shows that magnitude of *Italcable* TFP growth was relatively higher than that of *Sip*. Finally the paper also confirmed the need of a more complete measure of productivity than a single factor measure. According to the author, measurement of labor productivity alone can be misleading especially when capital and materials are growing at different rates than labor.

A year later, Sueyoshi (1995) studied seven *US regional Bell* operating companies. Extending the traditional DEA approach for comparing performances in different time periods, the author employs a data set spanning two time periods, 1985 and 1990. He also showed that the "overall time efficiency" can be broken down into four efficiency concepts: overall efficiency, scale efficiency, price efficiency and time efficiency. The study indicates that *regional Bell* has had problems with price efficiency but has done well in terms of scale efficiency.

Xiaoyu (1996) studied the productivity growth for *China's post and telecommunication industries*, using annual data from 1957 to 1993. He estimated Cobb-Douglass production function using the Maximum Likelihood method and the results shows that there was a declining trend during 1961 to 1982 with slight fluctuation for TFP performance. However, from 1983 onwards, this performance demonstrates the upward shift trend. He also concludes that scale economies play an important role in output growth next to capital.

In a more recent study, Asai and Nemoto (1999) measure productive efficiency of *NTT's (Nippon Telegraph and Telephone) eleven regional telecommunications business* in Japan, using the Malmquist productivity index. In general, their results indicate that the production frontier has expanded only in highly efficient business sectors such as Tokyo and Kanto regional telecommunications business sectors. In addition, the difference in Malmquist productivity index among the regional business sectors has increased over the period of the study.

In 2001, Daβler, Parker and Saal assessed the impact of market liberalization and privatization to productive efficiency of *European telecommunication* companies. Their study considers all the major European telecommunication operators between 1978 and 1998. Their results suggest that TFP levels have continued to increase over the years; however there is no consistent evidence of substantially higher TFP growth resulting from privatization and market liberalization.

At the same time, Calabrese, Campisi and Mancuso (2001) also studied the productivity performance of telecommunications industry for *eleven OECD European countries* over the period 1979 to 1998. Their analysis which adopts Malmquist productivity index showed that the overall TFP level is steadily increased over the considered period with an average rate of 8.1 percent a year. With regard to sources of growth, they concludes that technological change has been the more important source compared to overall efficiency change which have contributed 7 percent and 1.1 percent respectively. Moreover, their study also suggests that input output configuration is the major source of inefficiency rather than the size of operation.

Another paper written in the same year was by Uri (2001). His study focuses on the impact of US incentive regulation to level of productive efficiency in telecommunication companies covering the period from 1985 to 1998. Considering only *regional Bell operating companies* and using DEA approach, his results indicate that only after the year 1993, there is a consistent improvement in technical efficiency, even though the incentive regulation in form of price cap was implemented in 1991. Thus he concludes that some pattern of the improvement in technical efficiency subsequent to 1993 is attributable to incentive regulation.

In 2002, Uri performed similar study for the period of 1988 to 1999. Applying different method from his previous study, he estimates productivity parameters of distance function using the corrected ordinary least squares (COLS) approach. Even though his study indicates that TFP increased over the 1988 to 1999 period, the growth was more likely due to innovation rather than improvement in technical efficiency. His findings conclude that there was no improvement of technical efficiency before and after the implementation of the price cap incentive regulation.