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PRODUCTIVITY GROWTH IN THE MALAYSIAN MOBILE TELECOMMUNICATIONS INDUSTRY

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ABSTRACT

This paper analyzes the changes in productivity of Malaysian mobile telecommunications industry from 1996 to 2001. The data consist of a panel of five mobile service providers in Malaysia, namely Celcom, DiGi, Maxis, TimeCel and TM Cellular. Productivity is measured by the Malmquist index, using a Data Envelopment Analysis (DEA) technique. The Malmquist productivity measures are decomposed into two components: efficiency change and technical change index. The results showed that Total Factor Productivity (TFP) has increased significantly for the whole industry in which technical change has been the most important source of productivity growth to the mobile telecommunications industry. A low level of efficiency change in the industry indicates a great potential for the industry to increase its productivity through higher utilization of technology as well as technological knowledge dissemination. Continuous training programs to familiarize and improve technical expertise appear to offer better prospects for the mobile telecommunications industry to achieve greater productivity growth.

JEL classification: D24, L96

Key words: Total factor productivity, Telecommunication industry, Data envelopment analysis

1. INTRODUCTION

Many of the players in Malaysia's telecommunications sector were seriously affected by the economic crisis in the late 1990s. Despite this, there has been strong growth in the sector over the last decade. Fixed-line services increased from around 2 million in 1990 to a figure approaching 5 million in 2002, resulting in a penetration rate of close to 20 percent. The mobile market has been more spectacular, with an increase from 200,000 subscribers in 1990 to over 8 million by the end of 2002, an average annual growth rate of more than 45 percent. In addition, in the year 2000 mobile market penetration surpassed the 19.7 percent fixed-line penetration and to date the penetration rate for mobile services is 32.8 percent (Malaysian Communications and Multimedia Commission, MCMC).[1] Regardless of the progress, there is a dearth of research on the trend and sources of total factor productivity growth in the Malaysian telecommunications industry. While many earlier studies and research have been focusing on measuring Malaysian productivity growth at the aggregate level such as in agriculture, manufacturing and services, this paper is the first to explore productivity growth at disaggregated level, specifically on the Malaysian mobile telecommunication sector.

The structure of this paper is as follows. The next section provides an overview of the Malaysian mobile telecommunications industry. Section 3 discusses the methodology and data selection. Section 4 reports the findings and the last section concludes.

2. MALAYSIAN MOBILE TELECOMMUNICATIONS INDUSTRY: AN OVERVIEW

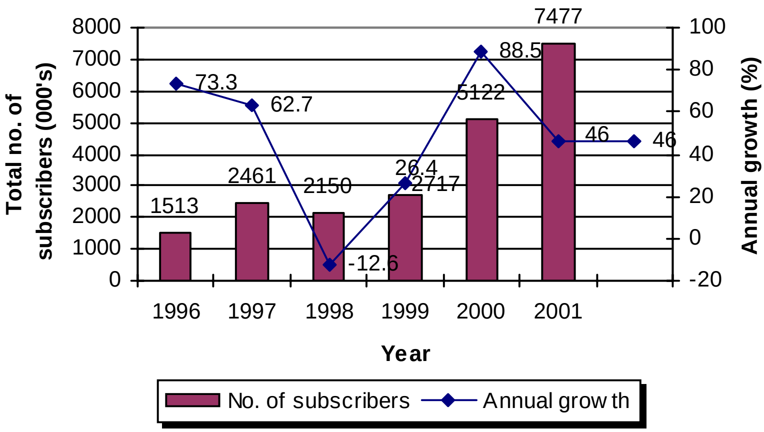
Mobile telecommunication services were first introduced in Malaysia in 1985, with the first mobile system using Nordic analogue technology, NMT450. Under the brand name of ATUR011, the system provided by Telekom Malaysia was claimed to be the first in Asia. With the installation of five mobile telephone exchanges and thousands of radio base stations, the service has provided almost nation-wide coverage.

In 1988, a new license was issued to STM Cellular Sdn. Bhd. to provide mobile services using more advanced analogue network ETACS 900. The following year, Alpine Resources Sdn. Bhd. (now Celcom Sdn. Bhd.) acquired all the shares held by the parent company, Syarikat Telekom Malaysia and took over the operation with the brand name of Celcom ART900. Within three years of operation, Celcom has successfully increased its subscriber base from 23,000 in 1990 to 123,330 in 1992, overtaking the incumbent market share.[2]

Later in 1993, the market was liberalized and opened to newcomers whereby six new licenses were issued. Given the availability of second-generation platforms featuring digital voice services and the emergence of several new mobile players, the cellular phone segment grew rapidly throughout the years. Since the launch of the first digital mobile phone in May 1995 by DiGi using the GSM 1800 MHz platform, the digital-based (GSM) subscribers have attained eight percent of the total market by the end of the same year. In 1998, the total number of analogue subscribers was overtaken by the GSM subscribers with more than one million subscribers. To date, the GSM-based subscribers have dominated the market with up to 96 percent of the whole market.[3] It is expected that by year 2005, all operators will only be offering the digital network platform to all subscribers.[4]

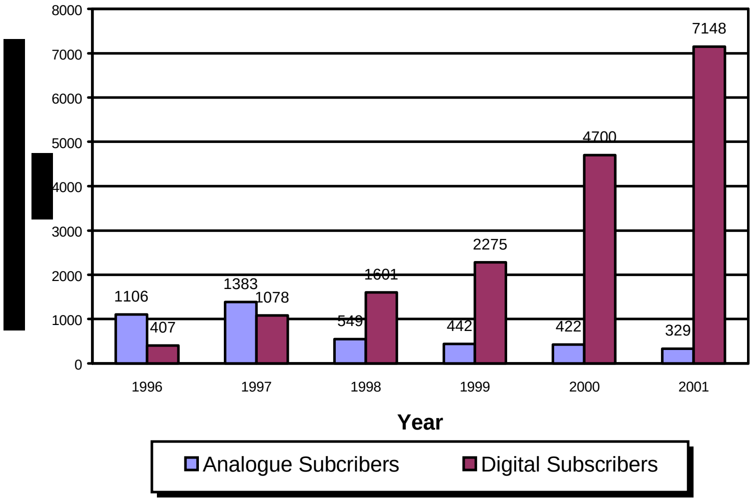
As for the whole industry, the total number of subscribers has increased from 1.513 million at the end of 1996 to 7.477 million in 2001 while mobile penetration has also increased from 7.1 percent to 31.1 percent during the same period. In terms of services, prepaid product remains the driving force behind this and accounted for 58.4 percent of total subscribers by the end of 2001, an increase of 9.1 percent from the year 2000.[5] Figures 1 to 3 summarize the development of mobile services in Malaysia.

FIGURE 1
Growth of Mobile Services



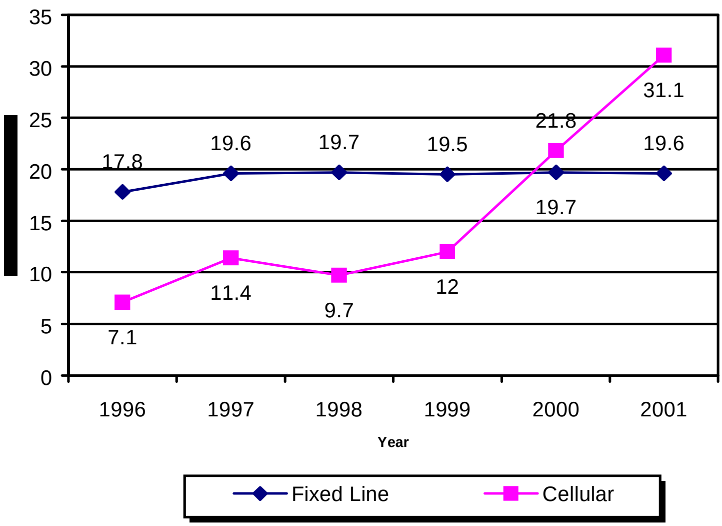
Source: Malaysian Communication and Multimedia Commission (MCMC)

FIGURE 2
Growth of Mobile Services by Network Platforms



Source: Malaysian Communication and Multimedia Commission (MCMC)

FIGURE 3
Penetration Rate for Fixed and Cellular
Telecommunication Network



Source: Malaysian Communication and Multimedia Commission (MCMC)

3. EMPIRICAL IMPLEMENTATION

3.1 METHODOLOGY

This study adopts the generalized output-oriented Malmquist index, developed by Fare et al. (1989), to measure the contributions from the progress in technology (technical change) and improvement in efficiency (efficiency change) to the growth of productivity in Malaysian mobile telecommunication industries. The Malmquist indexes are constructed using the Data Envelopment Approach (DEA) and estimated using a program developed by Coelli (1996) called DEAP version 2.1.[6]

Malmquist index is chosen as there are a number of desirable features for this particular study. It does not require input prices or output prices in their construction, which make the method particularly useful in situations in which prices are non-existent, or not publicly available. The method also does not require a behavioral assumption such as cost minimization or profit maximization, which makes it useful in situations where producers' objectives differ, or are unknown or unachieved.

Another attractive feature of the Malmquist index is that it can be further decomposed. This was first demonstrated by Fare et al. (1989) using the geometric mean formulation of the Malmquist index. Following this, Forsund (1991) decompose the simple version of the Malmquist productivity index into technical change and efficiency change.

Fare et al. (1994b) listed several traditional methods to calculate the Malmquist productivity index. But most of them require specification of a functional form for technology. Charnes et al. (1978) proposed the Data Envelopment Approach to construct a best-practice frontier without having to specify the production technology. Unlike traditional analysis techniques that look for the average path through the middle points of a series of data, DEA looks directly for a best-practice frontier within the data. Using a non-parametric linear programming technique, DEA takes into account all the inputs and outputs as well as differences in technology, capacity, competition, and demographics and then compares each firm with the best-practice (efficiency) frontier. According to Ali and Seiford (1993), DEA is a well-established non-parametric efficiency measurement technique which has been used extensively in over 400 studies of efficiency in management sciences.

To date, the Malmquist productivity indexes and DEA have been used in a variety of studies. These studies include aggregate comparisons of productivity between countries (Fare et al., 1994a) as well as various economic sectors such as agriculture by Tauer (1998), and Mao and Koo (1996), airlines by Alam and Sickles (1995), banking by Tulkens and Malnero (1996), and Avkiran (2001), electric utilities by Forsund and Kittelsen (1994), and telecommunications industry by Asai and Nemoto (1999), Calabrese, Campisi and Mancuso (2001), and Da˜ler, Parker and Saal (2002).

Asai and Nemoto (1999) measured productive efficiency of *NTT's (Nippon Telegraph and Telephone)* 11 regional telecommunication businesses in Japan, using the Malmquist productivity index. Their results indicate that the production frontier has expanded only in highly efficient regional telecommunications business sectors such as Tokyo and Kanto. In addition, the difference in Malmquist productivity index among the regional business sectors has increased over the period of the study.

Calabrese, Campisi and Mancuso (2001) on the other hand, studied the productivity performance of telecommunications industry for 11 OECD European countries over the period 1979 to 1998. Their analysis which adopts Malmquist productivity index showed that the overall TFP level increased steadily over the period with an average rate of 8.1 percent a year. With regard to sources of growth, they conclude that technical change was a more important source compared to efficiency change, which with growth contribution of 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.

In a more recent study, Daâler, Parker and Saal (2002) used the non-parametric approach to assess the impact of market liberalization and privatization on the productive efficiency of European telecommunication companies. Their study includes 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.

Formally, the Malmquist index of total factor productivity growth is given by:

1) $$M_o\left(x^t, y^t, x^{t+1}, y^{t+1}\right) = \left(\frac{D_o^t\left(x^{t+1}, y^{t+1}\right)}{D_o^t\left(x^t, y^t\right)} \frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_o^{t+1}\left(x^t, y^t\right)}\right)^{\frac{1}{2}}$$

where the notation $D_o^t\left(x^{t+1}, y^{t+1}\right)$ represents the distance between the period *t+1* observation to the period *t* technology. Following Fare et al. (1989) an equivalent way of writing the Malmquist productivity index (1) is

(2) $$M_o\left(x^t, y^t, x^{t+1}, y^{t+1}\right) = \frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_o^t\left(x^t, y^t\right)} \otimes$$

$$\left[\left(\frac{D_o^t\left(x^{t+1}, y^{t+1}\right)}{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}\right)\left(\frac{D_o^t\left(x^t, y^t\right)}{D_o^{t+1}\left(x^t, y^t\right)}\right)\right]^{\frac{1}{2}}$$

where the first ratio on the right hand side of equation (2) measures the change in relative efficiency (i.e., the change in how far observed production is from maximum potential production) from year *t* to *t+1*. The second term inside the brackets (geometric mean of the two ratios) captures the shift in technology (i.e., movements of the frontier function itself) between the two periods evaluated at x^t and x^{t+1}. That is,

(3) $$\text{Efficiency change} = \frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_o^t\left(x^t, y^t\right)}$$

(4) $$\text{Technical change} = \left[\left(\frac{D_o^t\left(x^{t+1}, y^{t+1}\right)}{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}\right)\left(\frac{D_o^t\left(x^t, y^t\right)}{D_o^{t+1}\left(x^t, y^t\right)}\right)\right]^{\frac{1}{2}}$$

Essentially, equation (3) investigates how well the production process converts inputs into outputs (catching up to the frontier) and equation (4) reflects improvement in technology. According to Fare et al. (1994a), improvements in productivity yield Malmquist index values greater than unity, while deterioration in performance over time is associated with a Malmquist index less than unity. The same interpretation applies to the values taken by the components of the overall TFP index. Improvement in the efficiency component yields an index value greater than one and is considered to be evidence of catching up (to the frontier). Values of the technical change component greater than one are considered to be evidence of technological progress. In empirical applications, four distance measures that appear in (2) are computed for each operator in each pair of adjacent time periods using mathematical programming technique.

Assume that there are $k = 1,\ldots, K$ firms that produce $m = 1,\ldots, M$ outputs $y^t_{k,m}$ using $n = 1,\ldots, N$ inputs $x^t_{k,n}$ at each time period $t = 1, \ldots, T$. Under DEA, the reference technology with constant returns to scale (CRS) at each time period t can be defined as

$$(5) \qquad G^t = \left[\left(x^t, y^t\right) : y^t_m \leq \sum_{k=1}^{K} z^t_k y^t_{k,m} \right] \qquad m = 1,\ldots, M$$

$$\sum_{k=1}^{K} z^t_k x^t_{k,n} \leq x^t_n \qquad n = 1,\ldots, N$$

$$z^t_k \geq 0 \qquad k = 1,\ldots, K$$

where z^t_k refers to the weight on each specific cross-sectional observation. Following Afriat (1972), the assumption of constant returns to scale may be relaxed to allow variable returns to scale by adding the following restriction:

$$(6) \qquad \sum_{k=1}^{K} z^t_k = 1 \qquad (VRS)$$

Following Fare et al. (1994a), this study used an enhanced decomposition of the Malmquist index by decomposing the efficiency change component, calculated relative to the constant returns to scale technology, into a pure efficiency component (calculated under the VRS technology) and a scale efficiency change component which captures changes in the deviation between the VRS and CRS technology. The subset of pure efficiency change measures the relative ability of operators to convert inputs into outputs while scale efficiency measures the extent the operators can take advantage of returns to scale by altering its size towards optimal scale.

To construct the Malmquist productivity index of firm k' between time t and t+1, the following four distance functions are calculated using DEA approach: , $D_o^{t+1}(x^t, y^t)$, $D_o^t(x^{t+1}, y^{t+1})$, $D_o^{t+1}(x^{t+1}, y^{t+1})$. These distance functions are the reciprocals of the output-based Farrell's measure of technical efficiency. The non-parametric programming models used to calculate the output-based Farrell measure of technical efficiency for each firm $k' = 1, \ldots, K$, is expressed as

(7)

subject to

$$\left[D_o^t\left(x_{k'}^t, y_{k'}^t\right)\right]^{-1} = \max \lambda^{k'}$$

(8) $\lambda^{k'} y_{k',m}^t \le \sum_{k=1}^{K} z_k^t y_{k,m}^t$ $\quad m = 1, \ldots, M$

$$\sum_{k=1}^{K} z_k^t x_{k,n}^t \le x_{k',n}^t \qquad n = 1, \ldots, N$$

$$\sum_{k=1}^{K} z_k^t = 1 \qquad (VRS)$$

$$z_k^t \ge 0 \qquad k = 1, \ldots, K$$

The computation of is similar to (8), where $t+1$ is substituted for t.

Construction of the Malmquist index also requires calculation of two mixed-distance functions, which is computed by comparing observations in one time period with the best practice frontier of another time period. The inverse of the mixed-distance function for observation k' can be obtained from

(9)

subject to

$$(10) \qquad \lambda^{k'} y^{t+1}_{k',m} \le \sum_{k=1}^{K} z^{t}_{k} y^{t}_{k,m} \qquad m = 1,\ldots M$$

$$\sum_{k=1}^{K} z^{t}_{k} x^{t}_{k,n} \le x^{t+1}_{k',n} \qquad n = 1,\ldots, N$$

$$\sum_{k=1}^{K} z^{t}_{k} = 1 \qquad (VRS)$$

$$z^{t}_{k} \ge 0 \qquad k = 1,\ldots, K$$

To measure changes in scale efficiency, the inverse output distance functions under the VRS technology are also calculated by adding (6) into the constraints in (8) and (10), based on VRS relative CRS technology. Scale efficiency change in each time period is the ratio of the distance function satisfying CRS to the distance function under VRS, while the pure efficiency change is defined as the ratio of the own-period distance functions in each period under VRS. Using these two distance functions with respect to the VRS technology, the decomposition of (2) becomes[7]

(11)

$$\left(\frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_o^{t}\left(x^{t+1}, y^{t+1}\right)}\right)^{\frac{1}{2}} 0 \left(\frac{D_o^{t}\left(x^{t}, y^{t}\right)}{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}\right) \; 0$$

$$\left(\frac{D_{oc}^{t+1}\left(x^{t}, y^{t}\right)}{D_o^{t+1}\left(x^{t}, y^{t}\right)} \frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_{oc}^{t+1}\left(x^{t+1}, y^{t+1}\right)} \frac{D_{oc}^{t}\left(x^{t}, y^{t}\right)}{D_o^{t}\left(x^{t}, y^{t}\right)} \frac{D_{oc}^{t}\left(x^{t+1}, y^{t=1}\right)}{D_o^{t}\left(x^{t+1}, y^{t+1}\right)}\right)^{\frac{1}{2}}$$

where

$$\left(\frac{D_o^{t+1}\left(x^{t}, y^{t}\right)}{D_o^{t}\left(x^{t}, y^{t}\right)}\right)\left(\frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_o^{t}\left(x^{t+1}, y^{t+1}\right)}\right)^{\frac{1}{2}} = \text{ technical change}$$

$$\left(\frac{D_o^t\left(x^t, y^t\right)}{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)} \right) \quad = \text{ pure efficiency change}$$

$$\left(\frac{D_{oc}^{t+1}\left(x^t, y^t\right)}{D_o^{t+1}\left(x^t, y^t\right)} \frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_{oc}^{t+1}\left(x^{t+1}, y^{t+1}\right)} \right) = \text{Scale Efficiency Change}$$

Note that when the technology in fact exhibits CRS, the scale change factor equals to one and it is the same decomposition as (2).

3.2 SAMPLE SELECTION

The sample for this study covers all the five mobile operators in Malaysia, which are Celcom, Digi, Maxis, TM Cellular and TimeCel.[8] However, only mobile services that operate using digital network platform are considered for this study. Hence, Celcom and TM Cellular analog services under the brand name of ATUR 900 and Mobikom 018 are not taken into consideration.[9] There are several reasons for selecting digital network over analog network platform:

1. A growing number of subscribers have shifted to more advanced, digital network platform that offers more value-added services.[10]
2. Analog network platform is not available to some operators, hence, it is more reliable to compare the productivity and efficiency of the operators using the common digital network platform.

Digital network services started their operation in mid-1995, with each operator offering the services at different period in that year. Thus, to avoid data inconsistency and data inavailability when the study was carried our, this study uses date 1996 to 2001.

3.3 INPUT AND OUTPUT SPECIFICATIONS

Studies on TFP of telecommunication industries show a wide variety of output and input specification. For example, Denny, Fuss and Waverman (1981) specify six aggregate outputs (local service, Bell toll, Trans toll, U.S. toll, other toll and miscellaneous) and three aggregate inputs (labor, capital and materials).[11] Nadiri and Schankerman (1981) specify one output (sum of adjusted operating revenues for service categories – local service, intrastate toll, interstate toll and miscellaneous category) and four inputs (labor, capital, intermediate materials, and research and development). Calabrese, Campisi and Mancuso (2001) evaluate the output by taking the total turnover and for inputs, two variables have been considered which are labor and capital. Daâler, Parker and Saal (2002) aggregate the output into physical output index and consider labor, capital and others as inputs variables. Uri (2001, 2002) specify three outputs (the number of local dial equipment minutes, the number of intraLATA billed access minutes, the number of interLATA billed access minutes) and three inputs (labor, capital and material). In summary, the literature encompasses a wide range of specifications which may have as much to do with data availability as with matters of principle.[12]

Due to data availability issues, only one output and four inputs are considered for this study, which are the number of subscribers as output, and total number of labor and capital as inputs. Capital inputs consist of three subcomponents, fixed capital stock of lands and buildings, total number of mobile switching centers (MSC) and radio base stations (RBS).[13] The primary sources of the data set are from the compilation made by MCMC from each respective operator. The data included are total number of digital subscribers, total number of employees and total number of MSC and RBS.[14] Secondary data such as total number of land and buildings are obtained from the respective operators' annual reports from the year 1996 to 2001. Since MSC and RBS equipments act as switching and transmission mechanism, it is reported to be the primary source of growth for telecommunication industries by the Telecommunications Industry Association (2000). Hence, these two equipments are very important input variables apart from the other variables for this study. On the other hand, the number of subscribers is chosen as the output variable since it wholly represents the main activities and output of the five operators. It also acts as a proxy to the variety of services (multiple outputs) offered by the operators such as international roaming, SMS and WAP services. Total number of labor includes all staff (full-time, part-time and contract) in the respective companies.

4. EMPIRICAL RESULT

4.1 PRODUCTION FRONTIER AND EFFICIENCY

Since the basic component of the Malmquist productivity index is related to measures of efficiency, the paper first reports efficiency change for the five operators from 1996 to 2001 in Tables 1 and 2 under constant returns to scale (CRS) and variable returns to scale (VRS).[15] A value of one imply that the firm is on the industry frontier in the associated year, while a value less than one imply that the firm is below the frontier or technically inefficient.[16]

TABLE 1
Efficiency of Operators, 1996-2001 (Constant Return to Scale)

Operator	1996	1997	1998	1999	2000	2001	1996-2001
Maxis	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Celcom	0.569	0.779	0.739	1.000	1.000	1.000	0.848
TM Cellular	0.997	1.000	0.615	0.706	0.926	0.758	0.834
DiGi	1.000	0.762	0.876	1.000	1.000	1.000	0.940
TimeCel	1.000	1.000	0.755	0.623	0.845	0.965	0.865
Mean	0.913	0.908	0.797	0.866	0.954	0.945	0.897

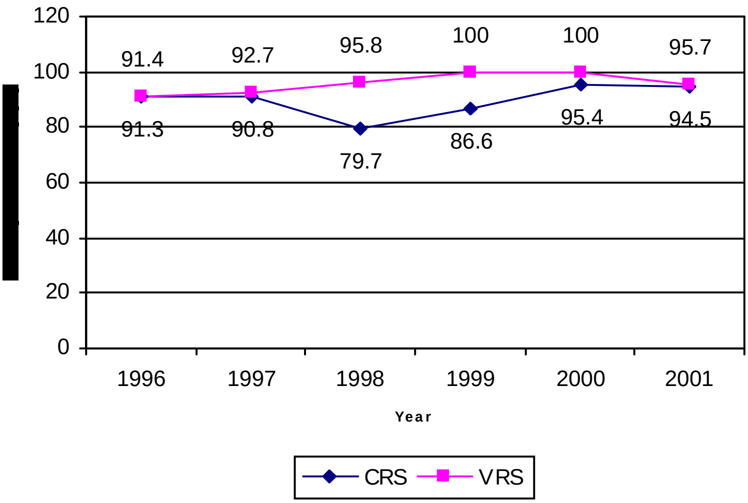
TABLE 2
Efficiency of Operators, 1996-2001 (Variable Return to Scale)

Operator	1996	1997	1998	1999	2000	2001	1996-2001
Maxis	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Celcom	0.569	0.873	0.862	1.000	1.000	1.000	0.884
TM Cellular	1.000	1.000	1.000	1.000	1.000	0.786	0.964
DiGi	1.000	0.762	0.930	1.000	1.000	1.000	0.949
TimeCel	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mean	0.914	0.927	0.958	1.000	1.000	0.957	0.959

The results show that Maxis is consistently efficient, both under constant returns to scale (CRS) and variable returns to scale (VRS). In fact, Maxis is the only operator on the frontier in CRS version of technology. TM Cellular and Celcom are the least efficient firms in the sample with average values of 0.834 (for CRS), and 0.884 (for VRS), respectively. The estimates also indicate that Celcom and DiGi have successfully kept pace with technically feasible production possibilities and increased their lead to the industrial production frontier for both versions of technology. DiGi was also efficient in most years, except in 1997 and 1998. TimeCel, on the other hand, was efficient in 1996 and 1997, but became inefficient in the last four years of the sample periods under CRS version. However, under the VRS version, TimeCel has recorded full efficiency together with Maxis for the period 1996 to 2001.[17]

The values in Tables 1 and 2 shows the percentage of the realized output level compared to the maximum potential output level at the given input mix. Thus, for example, TM Cellular produced 99.7 percent of its potential output and Celcom produced only 56.9 percent of its potential output in 1996 under CRS version. On the contrary, DiGi

FIGURE 4
Malaysian Mobile Telecommunications Industry Efficiency Performance, 1996-2001



produced 93 percent of its potential output and Celcom produced only 86.2 percent of its potential output in 1998 under VRS version.

As indicated by the weighted geometric means in Table 1, the average efficiency for the whole industry decreased continuously from 1996 to 1998. In 1999 and 2000, efficiency, however, has increased by 8.66 and 10.16 percent, respectively, but showed a decline again in 2001 by 0.06 percent. The year 1997 marked the least efficient period for the industry with only 79.7 percent output compared to its maximum potential output achievable with the observed input level.[18] In contrast, the results indicate a constant increase in average efficiency from 1996 to 2000 and a slight decline in 2001 under VRS version. In addition, the mean value of VRS version reflects higher potential output achieved with 95.9 percent compared to only 89.7 percent under CRS version.[19] Figure 4 gives a summary of the whole industry efficiency change from 1996 to 2001 under the two versions of technology.

4.2 PRODUCTIVITY PERFORMANCE OF INDIVIDUAL FIRMS

Tables 3 to 5 report the performance of operators in adjacent periods from 1996 to 2001 for TFP change and its two subcomponents, technical change and efficiency change. Note that a value of the Malmquist TFP productivity index and its components less than one implies a decrease or deterioration, while a value greater than one indicate an improvement in the relevant aspect.[20] Subtracting 1 from the number reported in the tables gives the average increase or decrease per annum for the relevant

TABLE 3
Operators Relative TFP Change Between
Time Period *t* and *t+1*, 1996-2001

Year	Maxis	Celcom	TM Cellular	DiGi	TimeCel
1996-1997	1.002	2.421	2.132	1.274	1.829
1997-1998	1.410	1.245	0.880	1.711	0.907
1998-1999	0.971	1.619	1.556	1.571	1.274
1999-2000	1.691	1.450	2.056	1.536	2.018
2000-2001	1.349	1.344	1.108	1.242	1.407
Mean	1.280	1.570	1.470	1.455	1.416

time period and performance measure.[21] Also note that these measures capture performance relative to the best practice in the relevant performance, or relative to the best practice in the sample.

Table 3 displays changes in the Malmquist-based Total Factor Productivity index. According to the results, Celcom and DiGi had positive productivity changes for all two adjacent years within the study period. In contrast, TM Cellular and TimeCel recorded deterioration in TFP for 1997-1998 and Maxis for 1998-1999, at the rate of 12 percent, 9.3 percent and 2.9 percent, respectively. Celcom had the highest average TFP growth at an annual average rate of 57 percent followed by TM Cellular with 47 percent, and DiGi with 45.5 percent. Overall, all the operators had increased their TFP on average by at least 25 percent per year for the period 1996-2001.

TABLE 4
Operators Relative Technical Change Between
Time Period *t* and t+1, 1996-2001

Year	Maxis	Celcom	TM Cellular	DiGi	TimeCel
1996-1997	1.002	1.769	2.126	1.673	1.829
1997-1998	1.410	1.314	1.433	1.488	1.201
1998-1999	0.971	1.195	1.354	1.376	1.544
1999-2000	1.691	1.450	1.601	1.536	1.488
2000-2001	1.349	1.344	1.326	1.242	1.232
Mean	1.280	1.403	1.553	1.455	1.426

The Malmquist TFP index was further decomposed into its two components, technical change and efficiency change. Table 4 presents the index values of technical progress/regress as measured by average shifts in the best-practice frontier from period *t* to *t+1*. The analysis indicates that there was technical progress for each individual firm from 1996 to 2001, except for Maxis which had technical regress (2.9 percent) for 1998-1999. TM Cellular recorded the highest change in technical progress among the operators with 112.6 percent from 1996 to 1997. This is consistent with the fact that TM Cellular had the highest average input growth with capital growth rate of 52.89 percent over the same period.[22]

Table 5 displays changes in relative output efficiency for each individual operators. The results indicate considerable variation across operators and across time. Only Maxis was efficient (and therefore showed no change in efficiency) in all periods from 1996 to 2001. For the other operators, there were periods with positive, negative or no changes in efficiency. Furthermore, the results showed that many operators improved their efficiency between 1998 to 1999, 1999 to 2000 and 2000 to 2001. For any two adjacent years between 1996 to 2001, our results showed that Celcom had the highest efficiency change in 1998-1999 with 35.4 percent, and TM Cellular recorded the worst efficiency deterioration with 38.5 percent in 1997-1998. On average, Celcom was the only firm to have recorded a positive efficiency change over the period of 1996 to 2001.

TABLE 5
Changes in Operators Relative Efficiency
Between Time Period *t* and *t+1*, 1996-2001

Year	Maxis	Celcom	TM Cellular	DiGi	TimeCel
1996-1997	1.000	1.369	1.003	0.762	1.000
1997-1998	1.000	0.948	0.615	1.150	0.755
1998-1999	1.000	1.354	1.149	1.141	0.825
1999-2000	1.000	1.000	1.310	1.000	1.357
2000-2001	1.000	1.000	0.819	1.000	1.142
Mean	1.000	1.119	0.947	1.000	0.993

In order to identify changes in scale efficiency, the efficiency change was further decomposed into pure efficiency change and scale efficiency change which is reported in Table 6. The results showed that scale efficiency appears to be an unimportant source of growth to efficiency change compared to pure efficiency change component for every firm in the sample. Average annual growth for 1996 to 2001 indicates that there are no changes for scale efficiency for 3 of the 5 operators in the sample. In addition, TM Cellular and TimeCel had a deterioration of scale efficiency by 0.007 percent for the respective period. Hence, the results suggest that size of a firm does not really matter in determining a firm's productivity and efficiency level. The results also indicate that Celcom had the highest growth in pure

TABLE 6
Changes in Efficiency Components by Operators, 1996-2001

Year	Maxis		Celcom		TM Cellular		DiGi		TimeCel	
	PEC	SEC	PEC	SEC	PEC	SEC	PEC	SEC	PEC	SEC
1996-1997	1.000	1.000	1.533	0.893	1.000	1.003	0.762	1.000	1.000	1.000
1997-1998	1.000	1.000	0.987	0.960	1.000	0.615	1.221	0.942	1.000	0.755
1998-1999	1.000	1.000	1.161	1.167	1.000	1.149	1.075	1.062	1.000	0.825
1999-2000	1.000	1.000	1.000	1.000	1.000	1.310	1.000	1.000	1.000	1.357
2000-2001	1.000	1.000	1.000	1.000	0.786	1.042	1.000	1.000	1.000	1.142
Mean	1.000	1.000	1.119	1.000	0.953	0.993	1.000	1.000	1.000	0.993

Notes: Pure Efficiency Change (PEC), Scale Efficiency Change (SEC) efficiency with 53.3 percent in period of 1996-1997, while DiGi recorded the highest deterioration with 23.8 percent.

4.3 FIRMS THAT INNOVATED

Although the results with respect to technical change as reported in Table 4 are suggestive of performance, they do not identify which firms are shifting their frontier over time. The technical change components of the Malmquist index only specify what happened to the frontier at the input level and mix of each firm, but not whether that firm actually caused the frontier to shift. Fare et al. (1994a) list the conditions to identify which firms have contributed to a shift in the industrial production frontier between year t and $t+1$. That is, a firm has contributed to a shift in the production frontier if its technical change is greater than one, and if its efficiency change is equal to one. Firms meeting these criteria can be considered as the 'innovators' in Malaysia's mobile telecommunications production.[23] According to Daâler, Parker and Saal (2002), firms which generate new value-added services will have an important impact on performance in terms of profitability and productivity. In other words, early adopters of new technology will appear to be technically more efficient than late adopters. Table 7 lists the firms that contributed to a shift in the frontier between 1996 and 2001.

TABLE 7
Shifting of Frontier for Firms, 1996-2001

Year	Maxis	Celcom	TM Cellular	DiGi	TimeCel
1996-1997	Yes	No	Yes	No	Yes
1997-1998	Yes	No	No	No	No
1998-1999	No	No	No	No	No
1999-2000	Yes	Yes	No	Yes	No
2000-2001	Yes	Yes	No	Yes	No
Mean	Yes	No	No	Yes	No

It is found that Maxis, TM Cellular and TimeCel were the initial innovators for the industry in 1996-1997. However, in the period of 1997-1998, only Maxis was the sole innovator in the industry. In addition, Maxis was the major innovator for the whole period of 1996 to 2001 with every year recording a push in the frontier except for the period 1998-1999. For this period, no firm was considered to be the innovator. In the subsequent periods, Celcom and DiGi joined Maxis to become the innovators in the industry. The surprising result is that TM Cellular, which had the highest average annual inputs growth, did not successfully maintain its position as the innovator for the period 1997-2001. The overall findings of this section not only support Daâler, Parker and Saal's (2002) earlier statement, but it also substantiate the grounds for Maxis to be considered as the only efficient frontier and the most efficient operator relative to others (refer table 5).

4.4 PRODUCTIVITY PERFORMANCE FOR THE ENTIRE INDUSTRY

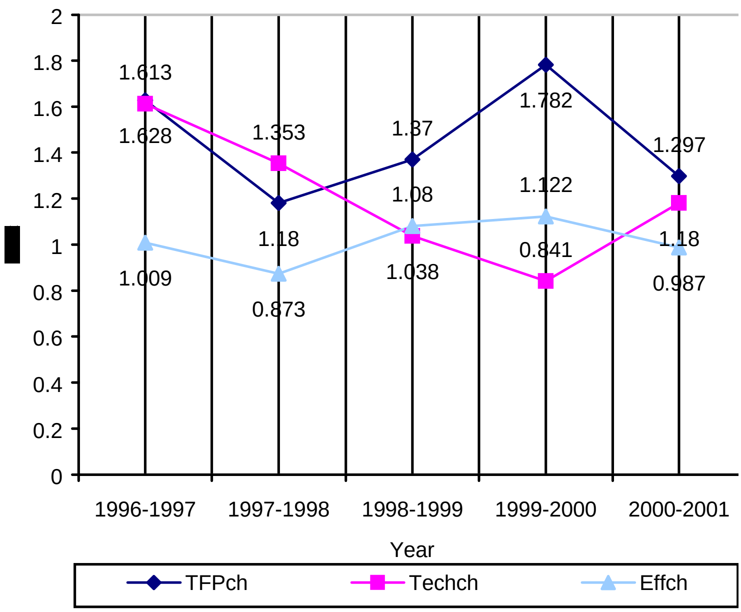
The performance of Malaysian mobile telecommunications industry between 1996 and 2001 is reported in Table 8. The columns in the table list the Malmquist index values of TFP change index, technical change, and the efficiency change component. The computed geometric mean shows that TFP has grown significantly over the years with an average increase of 43.5 percent per year. The highest increase in TFP occurs 1999-2000 with an improvement of 78.2 percent from 37 percent in the earlier period. For this period, the increase of TFP can be explained by the rapid diffusion of mobile services in terms of the growth of mobile network subscribers. Indeed, for the whole industry, the number of cellular subscribers has increased, on an average of 99.7 percent in this period.

TABLE 8
Malmquist Productivity Index for the Entire Industry, 1996-2001

Year	Malmquist TFP Change	Technological Change	Efficiency Change
1996-1997	1.628	1.613	1.009
1997-1998	1.180	1.353	0.873
1998-1999	1.370	1.269	1.080
1999-2000	1.782	1.589	1.122
2000-2001	1.297	1.315	0.987
Mean	1.435	1.421	1.010

The improvement in TFP was attributed by technical progress (42 percent), while efficiency change contributed only a small portion (1 percent) to the overall TFP growth (43 percent). The substantial growth in technical change and inconsistent growth in efficiency component suggest that the increase of TFP in Malaysian mobile telecommunications industry arose from the innovation in technology rather than the improvement in efficiency. This is evident from the increase in demand for accessibility as well as the need to improve the quality of services which have driven the growth in investment of capital input particularly the network infrastructures. Large increases in investments in both central office switching equipment and radio base stations were made during these periods. Unfortunately, these investments did not translate into efficiency improvement. Furthermore, values for the patterns of efficiency change are greater than one in almost all periods (refer Table 5) which indicate that, on average, input employed in the industry could be reduced by about 1 percent to maintain the same level of efficiency. Figure 5 presents the evolution over time of TFP and its components for the five mobile telecommunication

FIGURE 5
Malaysian Mobile Telecommunications Industry Productivity Performance, 1996-2001



operators as a whole, measured by the average of the geometric means of Malmquist productivity index for each period.

5. CONCLUSION

The results from this study have important implications for the Malaysian mobile telecommunications industry. For the industry as a whole, TFP has increased significantly (at least 25 percent) throughout the period of 1996 to 2001 with 1999-2000 recording the highest growth (78.2 percent). Indeed, this particular period also recorded the highest efficiency change at an annual rate of 12.2 percent. Moreover, beginning from this period, the telecommunications industry underwent an extensive improvement in efficiency with the maximum potential output for almost all the operators under the VRS technology.

Nevertheless, it should also be noted that the very presence of TFP growth in the industry was mainly due to technological improvement. This result therefore indicates that the Malaysian mobile telecommunication industry has great potential to further increase its output through an improvement in the efficiency component. Given the high technological advancement within the industry, the labor force should be well-equipped with knowledge in optimizing the technology available to give operators competitive advantage in the long term (Ketler and Willems, 2001). Thus, one area that needs particular emphasis is technological knowledge improvement and dissemination. Training and technical expertise should be constantly upgraded along with technological evolution. This can take the form of education and training program intended to improve managerial ability, or of extension programs designed to speed up the adoption of new technologies.

In addition, greater intensification of technology should also be accorded high priority. Existing technology has to be exploited further via infrastructure-sharing to reduce wastage resulting from under-utilization of assets. Though domestic roaming is underway and has been significant to the industry, a lot more can be done to speed up the technological adaptation and knowledge dissemination through healthy competition among the telecommunication companies and market liberalization of the industry. Further research needs to be directed to the policy formulation as well as its implications in order for the Malaysian mobile telecommunications industry to be in a better position in this fast growing and very competitive industry.

ENDNOTES

1. These figures are extracted from Communications and Multimedia Communications' online database which is available at http://www.mcmc.gov.my/mcmc/facts_figures/stats/index.asp. Retrieved on December 2002.

2. Figures obtained from Lee (2002).

3. Extracted from http://www.mcmc.gov.my/mcmc/facts_figures/stats/index.asp. Retrieved on December 2002.

4. All Mobikom 018 analog subscribers were successfully reassigned to TM Touch digital network on October 28, 2002.

5. These figures are extracted from Communications and Multimedia Communications' online database which available at http://www.mcmc.gov.my/mcmc/facts_figures/stats/index.asp. Retrieved on December 2002.

6. The DEAP software, written by Tim Coelli can be downloaded from his webpage www.uq.edu.au/~uqtcoell/

7. Subscript *c* under the distance function denotes what is measured with reference to CRS technology while unsubscripted distance functions are with reference to VRS technology.

8. There are several views regarding the minimum number of sample size for DEA. Stern, Mehrez and Borboy (1994) suggest that the sample size should be 3 times larger than the sum of the number of inputs and outputs. Dyson, Thanassoulis and Boussofiane (1998), on the other hand, view that there is a need for sample size larger than the product of number of inputs and outputs. Avkiran (2001), however, states that DEA can also be used with small sample size.

9. Celcom still offers the analog technology along with the digital technology. On the other hand, all Mobikom 018 subscribers have successfully been transferred to the TM Touch digital network on October 28, 2002.

10. As at 3rd quarter of 2002, digital mobile subscribers accounted for 96 percent of total mobile subscribers.

11. They also provide an alternative measure of aggregate output namely number of local calls, local service revenue, number of telephones, number of residential main stations, number of business main stations, number of toll calls and message toll revenue.

12. For a comprehensive literature reviews of TFP on telecommunications industry refer to Mohamad (2003).

13. MSC is a mobile telephone exchange site and RBS is a base transceiver station which provides a radio cell of one or more frequency channels for transmitting a mobile phone cell.

14. I am grateful to numerous officials from MCMC, particularly Mdm. Sulyna and Mr. Koay for their cooperation in gathering all the data requested.

15. Following Fare et al. (1994a), technical efficiency dealing with VRS is called pure efficiency.

16. DEAP ver. 2.1 reports the values from 0 to 1 where 1 indicates fully efficient. Fare et al. (1994a), Mao and Koo (1996) and Spitzer (1997), on the other hand, reports values greater than unity as technically inefficient production.

17. This fact conforms to the theoretical framework for VRS in which the number of efficient units will always be greater than that for CRS due to a loss in discriminating power (Avkiran, 2000).

18. During this period, output and inputs have shown a rise except for labor input which declines by 5.6 percent. This negative growth rate may be due to the impact of financial turmoil (1997-1998) which had affected not only telecommunications companies but companies in other industries as well.

19. This result is expected since there is a loss in discriminating power under VRS.

20. To interpret as a percentage change, take the natural logarithm of the index.

21. Since the Malmquist index is multiplicative, these averages are also multiplicative (i.e., they are geometric means).

22. Refer to Mohamad (2003) for the input growth pattern for all the respective operators from 1996-2001.

23. An innovator refers to the first firm to introduce new services using the latest available technology in the market.

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