Productivity and Efficiency Analysis of Telecommunications Industries: The Case of Asia-Pacific Countries

Shota Moriwaki[1], Akira Era[2], Makoto Osajima[3]

abstract

The purpose of this study is to compare efficiency levels in the telecommunications industries across the Asia-Pacific countries . We use Stochastic Frontier Analysis and estimate Cobb-Douglas and translog production function, using panel data sets. Our results suggest that during the period studied, we observe a positive and common technological change all over the region. In addition, US is the technological frontrunner and the differences between the TE values are explained by population, per capita GDP and the fixed phone penetration rate.

1. Introduction

The purpose of this study is to compare efficiency levels in the telecommunications industries across the Asia-Pacific countries—both developed and developing. In addition, we try to examine some factors that affect the estimated efficiency in these countries, using stochastic frontier analysis.

As many studies have shown, information and communications technology (ICT) investments have positive influences on economic growth. Further, in the pursuit of economic growth, ICT is regarded as one of the most important factors in both developed and developing economies. Against this backdrop, telecommunications carriers operate essential facilities as key infrastructure for the utilization of ICT. Besides, as many empirical studies show, since the 1990s, ICT has been identified in many countries as one of the crucial factors for economic growth, and telecommunications industries have been recognized as playing a significant role in the economic development of both developed and developing countries.[4] However, thus far, few studies have focused on the impact and role of the advances in ICT in the

[1] Associate Professor, Faculty of International Studies, Takushoku University

[2] Senior Lecturer, Shonai College of Industry and Technology

[3] Former Associate Professor, Graduate School of Global Information and Telecommunication Studies, Waseda University

[4] See ITU (2006).

developing world. Significantly, as the Asia-Pacific region includes many developing countries, the US is the technological frontrunner telecommunications sector would be expected to provide a springboard in the pursuit of further economic development. In order to examine the above issues, we applied a stochastic frontier (SF) production function to the telecommunications industries in the Asia-Pacific region, utilizing a panel data set covering the 1983–2007 period. We derive technical efficiency (TE) values through an estimation of the SF production function, and then compare the TE values across countries. The TE is a relative index that evaluates efficiency among economic entities on a scale of 0 to 1. A TE score of 1 shows that the entity adopts best practices, whereas 0 indicates the worst case.

Several studies estimate the SF production function for telecommunications carriers in industrialized countries. Battistoni et al. (2006) estimated the SF translog production function for EU countries, using a panel data set covering the 1995–2002 period. Their results show that the average TE values among the new EU members in the 1990s were somewhat higher than those of the old members, but are somewhat lower than the latter after 2000. Furthermore, a convergence of TE values among EU countries is also observed.[5] Similarly, Erber (2006) estimated the SF translog and Cobb-Douglas production functions for four EU countries (Germany, France, the UK, and the Netherlands) and the US, using panel data for the 1981–2002 period. The main difference between the estimation results of Battistoni et al. (2006) and Erber (2006) lies in the decomposition of capital stock, which the latter broke up into ICT and non-ICT. According to Erber (2006), ICT capital makes a positive contribution in the Cobb-Douglas production function. Furthermore, TE estimates form a "J-curve" over the period studied.[6] This type of J-curve means, in this context, that people cannot fully utilize ICT at first; however, as time goes on, they will be able to do so with the development of more skill. Both the above studies focused on developed countries

---

[5] Battistoni et al. (2006) also endeavored to estimate TE utilizing data envelopment analysis, and observed βconvergence of TE in EU countries as with the SF production function.

[6] The J-curve, defined by Paul David, indicates the adoption of general-purpose technology by industries in the course of economic development. See, for example, Helpman (1998) for general-purpose technology.

such as EU members and the US but did not address the developing regions. Unlike the preceding studies, we would like to focus more on the telecommunications sector of developing countries. Compared to others countries worldwide, developing countries in the Asia-Pacific region have shown superior economic performance since the 1980s. In this context, can the telecommunications industries, including the incumbent carriers, establish better management practices to ensure higher quality and affordable services? This question is the key to additional and sustainable growth.

By estimating the SF production function, we endeavored to ascertain whether the communication sector had access to common technologies across the countries of the Asia-Pacific region. Most technologies in the telecommunications sector are relatively advanced; to put it differently, ICT seems to be used intensively. Thus, the TE estimates indicate the efficiency of the diffusion of advanced technology from developed to developing countries across the Asia-Pacific region. Meanwhile, we must also consider common technological changes in the telecommunications industries during the estimation period. As a result of natural monopoly, a few enterprises in the telecommunications sector were previously owned by the state, and consequently grew to become large-sized businesses. After the 1980s, however, the technologies associated with the telecommunications industry have made considerable strides. It is commonly believed that such rapid changes in technology resulted in a more competitive environment. At that time, some of the governments of developed countries faced serious budget deficits, which forced them to introduce more efficiency in state-owned enterprises. These measures proved to be inadequate, and many state-owned enterprises were privatized. Privatization trends in developed countries continued with negotiations on entry to the WTO in the 1990s, which resulted in more privatization in developing countries.[7] In the Asia-Pacific region, privatization became more pronounced after the 1990s in the telecommunications sector. Many econometric studies examine whether

[7] For the relationship between the WTO and telecommunications reform, see Cowhey and Klimenko (2001).

privatization positively contributes to the performance of the telecommunications industry.[8] However, we could not obtain adequate data on privatization initiatives in all the Asia-Pacific countries that we intended to study. Therefore, we had to select the year trend as a proxy variable, which suggested the progress of privatization and other common innovations in the Asia-Pacific region.

We used a model that could estimate the SF production function and, simultaneously, explain the factors that had an impact on the value of TE.[9] Generally speaking, since most of the advanced technologies are exploited mainly in the developed world, the estimated TE is expected to be higher in the industrialized countries than in developing countries.

2. The model

According to Battese and Coelli (1995), we define the SF production function as follows:

$$\ln Y_{it} = x_{it}\alpha + V_{it} - U_{it} \quad (1)$$

where Y_{ti} is the production of the i-th country (i = 1, …, n) in the t-th year (t = 1, …, T); x_{it} is the input vector containing the logarithms of inputs; α is the vector of unknown parameters to be estimated; and V_{it} and U_{it} are both random variables, the former, especially, representing the statistical noise and the latter a non-negative value additionally indicating inefficiency. Furthermore, U_{it} and V_{it} are mutually independent. V_{it}, independently and identically, follow a normal distribution with the mean 0 and variance σ_v^2. On the other hand, U_{it} is also independent and identical, but unlike V_{it}, follows a half-normal distribution with the mean 0 and variance σ_u^2. In equation (1), the part of the deterministic component is $x_{it}\alpha$, and on account of the statistical noise, the frontier output is ($x_i\alpha + v_i$), the point at which the frontier output is placed over or under $x_i\alpha$, if it is depicted on the figure.[10] Consequently, we

[8] See, for example, Wallsten (2003), Wallsten (2004), and Lee (2008).

[9] See the discussion in this paper on the model used for the empirical study.

[10] See Coelli et al. (2005), Figure 9.1.

define the inefficiency U_{it} as the distance between the point of the frontier output and the point of the real output.

The technical inefficiency effect of the production function above could be specified as follows:

$$U_{it} = z_{it}\beta + W_{it} \quad (2)$$

where z_{it} denotes the explanatory variables associated with the technical inefficiency U_{it} and β a vector of unknown coefficients; W_{it} is defined by the truncation of the distribution with zero mean and variance of δ^2 as in Battese and Coelli (1995). In other words, equation (2) deals with some explanatory factors of U_{it}.

The parameters of equations (1) and (2) are estimated simultaneously by the maximum likelihood method. The likelihood function is expressed in terms of the variance parameters $\delta_S^2 \equiv \delta_V^2 + \delta^2$ and $\gamma \equiv \delta^2 / \delta_S^2$. The technical efficiency of the production function of the i-th country in the t-th year is defined as follows:

$$TE_{it} = \exp(-U_{it}) = \exp(-z_{it}\beta - W_{it}) \quad (3)$$

To examine the correlation between the stage of economic development and the estimated value of TE, we used dummy variables of 1 for high-income countries and 0 for other countries. Similarly, we assigned 1 for low-income countries and 0 for other countries as explained variables for TE[11]. In addition, to control for the potential market size of the studied countries, we added to the explanatory variables a dummy variable of 1 for countries with a population of more than 100 million and 0 for other countries. Finally, we verified whether the penetration rates of fixed and mobile phones affected the TE values. We assumed that the penetration rates of both phones indicated the state of development of infrastructure in the telecommunications industry. In this study, the capital stock, which is treated as a factor of

[11] We defined countries whose per capita GDP was above 20,000 US dollars as high-income countries and those whose per capita GDP was below 1,000 US dollars as low-income countries. In this case, we consider per capita GDP of 1,000 to 20,000 US dollars as the standard.

production in our estimated model, represents the infrastructure embodied in both fixed and mobile phone industries. Although externality is often assumed in capital stock, it appears stronger in infrastructure. In developing countries, the funds needed to build infrastructure are often not available. From the viewpoint of development strategy, it would be a rational choice for development planners to concentrate scant funds on industrial sectors that exhibit larger externality, and as a result, such sectors indicate higher TE values. Therefore, it is desirable that capital stock be measured for every sector in the industry. However, due to the constraint of data availability in our empirical research, we could not measure the capital stock in fixed and mobile phone industries separately. Hence, we adopted the penetration rates of both phone types as explanatory variables of TE, representing the development stage of infrastructure development in ICT.

In this study, our empirical models are as follows:

Stochastic Frontier Cobb-Douglas Production Function

$$\ln(Q)_{it} = \alpha_0 + \alpha_K \ln(K)_{it} + \alpha_L \ln(L)_{it} + \alpha_M \ln(M)_{it} + \alpha_t year + V_{it} - U_{it} \quad (4)$$

Stochastic Frontier Translog Production Function

$$\begin{aligned} \ln(Q)_{it} &= \alpha_0 + \alpha_K \ln(K)_{it} + \alpha_L \ln(L)_{it} + \alpha_M \ln(M)_{it} + \alpha_t year \\ &+ \alpha_{KL} \ln(K)_{it} \ln(L)_{it} + \alpha_{KM} \ln(K)_{it} \ln(M)_{it} + \alpha_{LM} \ln(L)_{it} \ln(M)_{it} \\ &+ \frac{1}{2}\alpha_{KK} (\ln K)^2_{it} + \frac{1}{2}\alpha_{LL} (\ln L)^2_{it} + \frac{1}{2}\alpha_{MM} (\ln M)^2_{it} + V_{it} - U_{it} \end{aligned} \quad (5)$$

Inefficiency Model:

$$TE_{it} = \beta_0 + \beta_1 DLI_{it} + \beta_2 DHI_{it} + \beta_3 HP_{it} + \beta_4 FP + \beta_5 MP + W_{it} \quad (6)$$

In the production function, Q_{it} is the output of the i-th country in the t-th year, K_{it} the capital stock, L_{it} labor power, and M_{it} raw material. In the TE effect model, DLI_{it}, DHI_{it}, and HP_{it} indicate the dummy variables, respectively, of low-income countries, where GDP per capita is below 1,000 US dollars, high-income countries, where GDP per capita is more than 20,000 US dollars, and large-population countries, where the population is more than 100 million. In addition to these variables, FP_{it}

and MP_{it} denote the penetration rates of fixed and mobile phones, respectively, considered as indexes of market constitution in the telecommunications industries of the countries studied.

In this study, we estimate the Cobb-Douglas and translog production function. The Cobb-Douglas production function is a special form of the translog production function, and Cobb-Douglas function is in a restrictive form. Because the translog production function has more flexible and general characteristics, it has been used in many empirical studies. We assume that there is no bias or acceleration of technological change in the translog production function, which we estimate because of protection against incorrect estimation results from multicollinearity, as in Battistoni et al. (2006). In the estimation of the translog production function, we use differences from the mean as the data.

Although there are several SF models for the panel data set, we select the model presented in Battese and Coelli (1995) for this analysis because their model examines the explanatory variables based on the TE values, U_{it}.

3. Data

In this article, we apply semi-macro-level, or industry-level, data. The data for our estimation of the SF production function come from three databases: the World Development Indicators (WDI), the World Telecommunication/ICT Indicators Database, and Penn World Table (PWT), version 6.3. In this study, though, we have mostly used data from the WDI. WDI data are missing in some countries, and in such cases, we collected data from the PWT instead. The details are as follows.

- Aggregate output: Telecommunications revenue at 2000 prices. Since we could not obtain deflators for the telecommunications industries of the Asia-Pacific countries, we used the countries' GDP deflators, obtained from the WDI, for each year in order to construct the output.
- Capital stock: In this study, we used the gross concept to estimate capital stock because of the lack of depreciation data, so the capital stock in any given year is the sum of investments accumulated

from previous years through the period of endurance. The estimates are constructed as $\sum_{t=0}^{T} I_t$,

where I is the telecommunications investment at 2000 prices and T represents the durable years (18). T is derived from the durable years for the capital stock of the Japanese telecommunications industryies as provided in Social Capital of Japan 2007 (Cabinet Office, 2007). The deflator used in the construction of the capital stock is the value estimated by the ratio of the current gross capital formation to the real gross capital formation from the WDI. When investment data are missing, we would estimate the linear interpolation method.

- Labor force: The total number of telephone employees.
- Raw materials: The total number of fixed and mobile cellular phone subscribers. The raw materials in the telephone industries appear to include everything except the expenses on the labor force and capital input, but we could not obtain them from any published databases such as those used here. Therefore, we apply the total number of telephone subscribers as the proxy for raw materials, following Nemoto and Asai (2002).[12]
- Year: We used the year trend as the proxy variable for the common technical changes in the countries studied.
- PPP: The local currency per international dollar at 2000 rates of exchange, obtained from the WDI.
- Penetration rate of fixed phone: We used the number of main fixed telephone lines per 100 inhabitants from the World Telecommunication/ICT Indicators Database.
- Penetration rate of mobile phone: We used the number of mobile phone subscriptions per 100 inhabitants from World Telecommunication/ICT Indicators Database.

The data for the explanatory variables of SF production function are shown in Table 1. In this study, since we cannot use all panel data, we estimate the SF production function using unbalanced panel data.

---

[12] According to Nemoto and Asai (2002), the expenses for raw materials in the Telecommunications industry vary in proportion to the number of telephone subscribers.

Table 1: Summary statistics of the data

Australia (t=23, from 1983 to 2007)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	12,150	42,069	89	13,302	47.26	30.04	19,164	18,370
Std.dev	5,290	12,807	9	7,701	5.03	32.12	2802.45	1,599
Maximum	22,261	72,153	104	31,020	53.30	102.49	23936.44	21,015
Minimum	5,203	28,565	72	5,592	36.69	0.03	15873.95	16,264

Japan (t=25, from 1983 to 2007)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	68,575	342,299	223	92,075	44.84	28.22	34,166	124,845
Std.dev	23,906	7,865	71	43,625	4.70	31.60	4,380	2,646
Maximum	120,642	354,921	325	158,571	52.11	83.88	40,745	127,773
Minimum	45,493	328,798	114	42,906	35.92	0.02	25,241	119,259

Korea (t=22, from 1983 to 2006)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	21,050	79,317	69	31,167	49.64	43.20	9,392	44,960
Std.dev	14,838	39,480	18	21,358	8.73	47.91	3,013	2,570
Maximum	47,936	141,542	109	62,629	59.15	132.68	14,469	48,297
Minimum	4,337	20,678	43	4,810	29.57	0.18	4,049	39,910

Taiwan (t=9, from 1999 to 2007)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	15,344	50,694	39	35,103	60.08	95.32	22,110	22,520
Std.dev	2,037	7,484	2	5,076	3.24	18.70	2,379	300
Maximum	17,258	58,844	43	39,714	63.42	114.14	26,204	22,917
Minimum	11,486	38,094	37	23,585	54.52	52.24	19,342	22,010

Malaysia (t=11, from 1994 to 2004)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	816	2,868	26	9,420	18.59	22.13	3,920	22,696
Std.dev	2,484	7,278	3	5,089	1.81	18.68	309	1,712
Maximum	11,614	38,429	30	19,057	20.15	58.69	4,455	25,191
Minimum	4,111	16,898	21	3,435	14.43	2.88	3,366	20,079

Macao (t=8, from 2000 to 2007)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	366	827	1.1	597	38.48	91.17	19,827	474
Std.dev	67	97	0.1	225	0.92	46.35	5,964	25
Maximum	490	969	1.2	972	39.87	165.10	30,556	513
Minimum	280	681	1.0	318	37.00	31.80	13,839	441

China (t=13, from 1993 to 2007)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	90,393	52,113	615	352,689	13.49	13.51	1,039	1,255,110
Std.dev	56,798	14,241	159	339,674	10.48	15.24	413	47,903
Maximum	170,509	72,153	980	912,943	27.79	41.19	1,811	1,318,310
Minimum	15,938	36,043	445	17,970	1.45	0.05	536	1,178,440

Hong Kong (t=15, from 1993 to 2007)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	6,891	14,342	28	8,642	55.43	72.45	26,376	6,560
Std.dev	1,167	5,076	9	3,740	2.69	48.37	3,396	308
Maximum	8,537	21,252	39	14,876	59.15	149.20	34,041	6,926
Minimum	4,656	6,170	18	3,283	50.03	4.86	23,206	5,901

Indonesia (t=17, from 1988 to 2004)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	6,014	28,987	40	8,832	2.12	2.07	763	195,198
Std.dev	2,878	6,942	2	10,927	1.34	3.82	115	14,186
Maximum	12,745	43,992	44	40,713	4.71	13.78	906	217,587
Minimum	2,350	20,036	37	838	0.47	0.01	534	171,994

New Zealand (t=9, from 1999 to 2007)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	3,123	7,710	7	4,552	45.30	69.34	14,177	4,020
Std.dev	458	441	2	946	2.31	22.54	786	147
Maximum	4,159	8,062	10	5,998	48.45	101.74	15,178	4,228
Minimum	2,743	6,796	5	3,228	41.81	36.86	12,959	3,835

Philippines (t=5, from 2000 to 2004)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	7,148	26,591	22	21,181	4.18	22.45	1,010	80,795
Std.dev	1,857	2,722	1	10,337	0.09	12.24	41	2,458
Maximum	10,033	30,158	23	36,373	4.29	40.35	1,073	83,911
Minimum	5,131	22,983	20	9,516	4.04	8.52	975	77,689

Singapore (t=18, from 1983 to 2004)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	3,174	7,800	9	2,670	40.73	29.72	18,717	3,561
Std.dev	1,252	1,667	2	1,795	6.26	34.09	4,180	502
Maximum	4,874	9,943	13	5,848	48.44	93.40	25,651	4,176
Minimum	1,028	4,473	6	694	26.85	0.00	10,386	2,681

Thailand (t=8, from 1998 to 2005)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thousand)
Mean	9,883	31,555	26	25,286	9.81	30.23	2,106	63,635
Std.dev	3,635	4,653	3	26,515	1.02	40.55	251	1,891
Maximum	17,276	37,458	31	86,090	11.00	123.77	2,594	66,979
Minimum	5,567	24,595	22	7,015	8.36	3.28	1,827	61,399

Bangladesh (t=7, from 1995 to 2001)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thousand)
Mean	677	1,784	19	561	0.33	0.12	314	135,690
Std.dev	184	168	1	284	0.06	0.14	22	5,478
Maximum	942	2,064	20	1,085	0.43	0.40	346	143,289
Minimum	454	1,582	16	289	0.25	0.00	285	128,086

India (t=19, from 1983 to 2001)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	11,212	50,548	379	12,535	1.24	0.07	343	882,497
Std.dev	733	2,788	47	12,341	1.02	0.16	70	93,641
Maximum	25,722	107,568	429	45,076	3.71	0.63	469	1,032,473
Minimum	3,047	18,753	298	2,668	0.36	0.00	253	734,072

Pakistan (t=8, from 2000 to 2007)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	6,099	20,369	438	19,275	2.75	9.40	578	150,274
Std.dev	1,780	726	537	23,029	0.46	13.80	47	8,597
Maximum	9,154	21,081	1,367	67,767	3.34	38.41	654	162,481
Minimum	4,264	19,022	67	3,360	2.14	0.21	533	138,080

Sri Lanka (t=22, from 1983 to 2005)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	560	1,544	9	745	1.87	1.85	689	17,669
Std.dev	562	1,412	1	1,157	1.73	4.04	160	1,198
Maximum	2,149	4,378	12	4,606	6.00	16.21	1,009	19,668
Minimum	47	197	7	74	0.46	0.00	482	15,591

United States (t=21, from 1984 to 2004)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	210,659	493,378	1,009	206,547	57.56	18.16	0	263
Std.dev	67,128	66,964	132	84,725	6.91	20.51	0	19
Maximum	334,312	624,286	1,302	362,510	67.75	62.56	0	293
Minimum	131,025	430,326	879	112,642	46.78	0.04	0	236

Mongolia (t=3, from 2004 to 2006)

	Q (million USD)	K (million USD)	L (thousand)	M (thousand)	penetration of fixed phones(%)	penetration of mobile phones(%)	GDP per capita (USD)	Population (thounsand)
Mean	279	312	5	741	5.80	22.13	588	2,551
Std.dev	28	65	0	181	0.19	6.34	37	35
Maximum	311	383	5	934	5.93	28.94	626	2,585
Minimum	260	255	5	575	5.58	16.40	553	2,515

Sources: World Development Indicator and ITU World Telecommunication/ICT Indicators Database; own calculations.

4. Estimation results

We estimate the Battese and Coelli (1995) model, using FRONTIER 4.1, which is a free software for estimating SF analysis, openly provided in the website of the Center for Efficiency and Productivity Analysis (CEPA). Estimation results of the SF Cobb-Douglas and translog production functions utilizing the Battese and Coelli (1995) model are reported in Table 2. From the table, almost all the estimated parameters of the factor of production of the Cobb-Douglas production function are significantly positive. In addition, from the estimated results of the translog production function, with the exception of the estimated parameters α_{KM} and α_{MM}, the estimated parameters of the factor of production are all significant.

From the estimated result of the Cobb-Douglas production function, the sum of the estimated parameters of the production factor ($\alpha_K + \alpha_L + \alpha_M$) indicates a value of 0.96. Testing H_0:$\alpha_K + \alpha_L + \alpha_M = 1$ utilizing the likelihood ratio test, we can reject H_0 at the 5% level. In the case of the translog production function, the hypothesis of the constant return to scale is rejected at the 5% level in the neighborhood of the mean value in the data utilized in this study, and like the estimated results of the Cobb-Douglas production function, the sum of the estimated parameters of the production factor indicates a value of 0.96. The sum of the estimated parameters of the production factor in both cases fall below unity. Therefore, we may add that a situation of diminishing returns to scale is established in the telecommunications industry. Although the telecommunications industry was formerly thought to be a natural monopoly, such a characterization appeared to be unsuitable for the estimated results in the Asia-Pacific region. The results of diminishing returns to scale are similar to the estimated results of Erber (2006). Additionally, in both results, the estimated parameter of the year trend is significantly positive. This indicates that during the period studied, all the Asia-Pacific countries witnessed technological progress.

Table 2: The result of regression estimates

Cobb-Douglas Production Function			*Translog Production Function*		
parameter	*coefficient*	*t value*	*parameter*	*coefficient*	*t value*
α_0	5.731	17.15	α_0	24.669	373.58
α_K	0.342	15.08	α_K	0.257	8.50
α_L	0.221	6.60	α_L	0.176	5.73
α_M	0.400	11.99	α_M	0.525	14.60
α_t	0.016	3.66	α_t	0.009	2.17
			$\frac{1}{2}\alpha_{KL}$	0.095	3.76
			$\frac{1}{2}\alpha_{KM}$	0.044	1.60
			$\frac{1}{2}\alpha_{LM}$	0.055	2.26
			$\frac{1}{2}\alpha_{KK}$	-0.106	-5.06
			$\frac{1}{2}\alpha_{LL}$	-0.067	-4.31
			$\frac{1}{2}\alpha_{MM}$	-0.010	-0.62
β_0	-0.124	-0.55	β_0	0.659	7.09
β_1	0.620	2.67	β_1	0.118	1.60
β_2	-0.273	-1.78	β_2	-0.148	-3.12
β_3	-0.065	-0.79	β_3	-0.164	-2.97
β_4	-0.028	-5.03	β_4	-0.004	-2.48
β_5	0.011	5.34	β_5	0.002	1.89
$\hat{\sigma}_S^2$	0.102	4.32	$\hat{\sigma}_S^2$	0.039	9.29
$\hat{\gamma}$	0.601	4.34	$\hat{\gamma}$	0.915	9.08
Log (likelihood)		10.431	*Log (likelihood)*		67.02

With respect to the inefficiency model, the dummy variable of high-income countries has significant positive effects on efficiency in both production function models. This means if the per capita GDP level of a country would be over a certain level, in this case 20,000 US dollars, the efficiency of the telecommunications industry would increase. The penetration of fixed phones, which may indicate the level of infrastructure related to fixed telephones, has significant positive effects on efficiency, but as to mobile phones, the contrary result is shown in both estimations. This indicates that the construction of infrastructure may be more important for fixed phones than mobile phones.

Table 3: Hypothesis tests

Null hypothesis	χ^2 statistics	Critical $\chi^2_{k,0.95}$	Decision
(1) $H_0 : \alpha_{ij} = 0$	113.17	$\chi^2_{6,\ 0.95} = 11.91$	Reject H_0 :
(2) $H_0 : \gamma = 0$	5.43	$\chi^2_{1,\ 0.95} = 2.71$	Reject H_0 :
(3) $H_0 : \beta_1 = ...\beta_5 = 0$	11.65	$\chi^2_{5,\ 0.95} = 10.37$	Reject H_0 :
(4) $H_0 : \gamma = \beta_0 = ...\beta_5 = 0$	53.26	$\chi^2_{7,\ 0.95} = 13.40$	Reject H_0 :

Note: Mixed $\chi^2_{k,0.95}$ values are taken from Kodde and Palm (1986), Table 1.

To confirm that both estimated results are different, we need to test some hypotheses using the results. At the beginning, the hypothesis of the Cobb-Douglas production function is rejected at the 5% level according to the result in the first column of Table 3. It may be most desirable to use the results of the translog production function to consider the estimated results. We use the translog production function of the Battese and Coelli (1995) model for the calculation of TE. To check the utilization of the SF model, the results—whether the null hypothesis can be rejected by the likelihood ratio test—are reported from the second to the fourth column in Table 3. From the results in the second column of Table 3, we can confirm that the Battese and Coelli (1995) model is a better estimation method than the ordinary least square method. The result in the third column indicates that some variables used in the estimation could explain the inefficiency U . The results in the last column show that our method is superior to the estimation of the translog production function, with no inefficiency found by the simple ordinary least square method. According to these results, we can conclude that the estimation results of the SF translog production function based on the Battese and Coelli (1995) model are quite excellent.

From the estimation results of the SF translog production function in Table 2, unlike those of Cobb-Douglas, the dummy variable of low-income countries with per capita GDP below 1000 US dollars is not significant, but the dummy variable of large-population countries (population above 100 million) has significant positive effects on efficiency. This result indicates that the potential market scale affects efficiency positively.

Table 4: The estimation results of TE

Country	Year	TE
Australia	1983	0.489
	1984	0.505
	1985	0.517
	1986	0.537
	1987	0.533
	1988	0.563
	1989	0.608
	1990	0.616
	1991	0.631
	1992	0.666
	1993	0.652
	1994	0.663
	1995	0.667
	1996	0.647
	1997	0.660
	1998	0.599
	1999	0.591
	2000	0.587
	2001	0.548
	2002	0.650
	2003	0.610
	2005	0.597
	2007	0.541
	average	0.595

Country	Year	TE
Japan	1983	0.747
	1984	0.740
	1985	0.726
	1986	0.707
	1987	0.706
	1988	0.683
	1989	0.669
	1990	0.672
	1991	0.662
	1992	0.663
	1993	0.679
	1994	0.699
	1995	0.709
	1996	0.721
	1997	0.757
	1998	0.754
	1999	0.792
	2000	0.780
	2001	0.667
	2002	0.912
	2003	0.974
	2004	0.924
	2005	0.733
	2006	0.727
	2007	0.736
	average	0.742

Country	Year	TE
Korea	1983	0.510
	1986	0.477
	1987	0.524
	1988	0.504
	1989	0.474
	1990	0.471
	1991	0.488
	1992	0.493
	1993	0.494
	1994	0.485
	1995	0.518
	1996	0.599
	1997	0.577
	1998	0.536
	1999	0.586
	2000	0.645
	2001	0.677
	2002	0.593
	2003	0.676
	2004	0.731
	2005	0.737
	2006	0.733
	average	0.570

Country	Year	TE
United States	1984	0.910
	1985	0.924
	1986	0.940
	1987	0.918
	1988	0.913
	1989	0.947
	1990	0.924
	1991	0.899
	1992	0.905
	1993	0.892
	1994	0.864
	1995	0.841
	1996	0.839
	1997	0.916
	1998	0.898
	1999	0.880
	2000	0.856
	2001	0.811
	2002	0.763
	2003	0.871
	2004	0.854
	average	0.884

Country	Year	TE
Malaysia	1994	0.552
	1995	0.559
	1996	0.648
	1997	0.661
	1998	0.643
	1999	0.646
	2000	0.632
	2001	0.686
	2002	0.672
	2003	0.603
	2004	0.594
	average	0.627

Country	Year	TE
Taiwan	1999	0.503
	2000	0.508
	2001	0.492
	2002	0.510
	2003	0.511
	2004	0.540
	2005	0.557
	2006	0.546
	2007	0.539
	average	0.523

Country	Year	TE
Macao	2000	0.450
	2001	0.439
	2002	0.468
	2003	0.453
	2004	0.448
	2005	0.464
	2006	0.457
	2007	0.502
	average	0.460

Country	Year	TE
Thailand	1998	0.499
	1999	0.567
	2000	0.600
	2001	0.584
	2002	0.601
	2003	0.499
	2004	0.469
	2005	0.458
	average	0.535

Country	Year	TE	Country	Year	TE	Country	Year	TE	Country	Year	TE
China	1993	0.683	Hong Kong	1993	0.943	Indonesia	1988	0.579	Singapore	1983	0.495
	1994	0.690		1994	0.919		1989	0.545		1988	0.624
	1995	0.902		1995	0.903		1990	0.596		1989	0.640
	1996	0.853		1996	0.899		1991	0.625		1990	0.646
	1997	0.749		1997	0.874		1992	0.645		1991	0.643
	1998	0.873		1998	0.667		1993	0.677		1992	0.675
	1999	0.833		1999	0.682		1994	0.721		1993	0.718
	2002	0.688		2000	0.678		1995	0.699		1994	0.797
	2003	0.624		2001	0.624		1996	0.571		1995	0.857
	2004	0.591		2002	0.628		1997	0.533		1996	0.783
	2005	0.571		2003	0.593		1998	0.434		1997	0.841
	2006	0.548		2004	0.613		1999	0.420		1998	0.759
	2007	0.555		2005	0.617		2000	0.469		1999	0.844
	average	0.705		2006	0.618		2001	0.394		2000	0.779
				2007	0.601		2002	0.432		2001	0.766
				average	0.724		2003	0.450		2002	0.776
							2004	0.427		2003	0.737
							average	0.542		2004	0.714
										average	0.727

Country	Year	TE	Country	Year	TE	Country	Year	TE	Country	Year	TE
Sri Lanka	1983	0.384	India	1983	0.537	New Zealand	1999	0.650	Pakistan	2000	0.489
	1984	0.390		1984	0.500		2000	0.644		2001	0.467
	1985	0.429		1985	0.470		2001	0.605		2002	0.440
	1986	0.444		1986	0.558		2002	0.606		2003	0.451
	1987	0.356		1987	0.641		2003	0.711		2004	0.407
	1988	0.348		1988	0.707		2004	0.658		2005	0.401
	1989	0.434		1989	0.676		2005	0.742		2006	0.355
	1990	0.464		1990	0.643		2006	0.503		2007	0.319
	1991	0.547		1991	0.594		2007	0.463		average	0.416
	1992	0.548		1992	0.577		average	0.620	Bangladesh	1995	0.535
	1993	0.534		1993	0.587	Philippines	2000	0.436		1996	0.453
	1994	0.458		1994	0.577		2001	0.410		1997	0.507
	1995	0.602		1995	0.555		2002	0.423		1998	0.564
	1996	0.633		1996	0.543		2003	0.406		1999	0.536
	1997	0.486		1997	0.521		2004	0.445		2000	0.551
	1998	0.466		1998	0.539		average	0.424		2001	0.523
	1999	0.422		1999	0.478	Mongolia	2004	0.735		average	0.524
	2001	0.404		2000	0.443		2005	0.630			
	2002	0.397		2001	0.413		2006	0.564			
	2003	0.407		average	0.556		average	0.643			
	2004	0.415									
	2005	0.482									
	average	0.457									

We report the estimation results of TE using the translog SF production function in Table 4. The mean value of TE in the US is the largest among the countries studied, while the mean values of Japan ,Singapore, Hong Kong, and China are relatively high—above 0.7. We can thus conclude that the US is the technological frontrunner in the telecommunications industries of the Asia-Pacific region. In addition, we can observe the remarkable increasing trend of the TE in Korea during the period studied. In the early 1980s, the telecommunications industry of Korea was positioned below the production frontier. However, it caught up with the technological level of the advanced countries over a period, from the 1980s to the 2000s. We may conclude that the high economic growth of Korea during the period studied may be associated with the technological progress in the telecommunications industry.

Meanwhile, efficiency values of the South Asian countries are relatively low and has stagnated during the years studied. In particular, the TE value has declined sharply in Pakistan after 2000. In the South Asian countries, the penetration rate of the fixed phone is much lower than in other countries during the period studied. The capital stock relevant to the fixed phone is the most fundamental infrastructure in the telecommunications sector, and the delay in the development of the infrastructure relating to the fixed phone may lead to lower TE values in South Asian countries.

5. Conclusion

The estimation results of the SF translog production function are statistically useful. We can therefore confirm that flexible technology is used in the telecommunications industries across the Asia-Pacific region. In the Asia-Pacific region, some advanced countries effectively utilize sophisticated technology in the telecommunications industries. In particular, the US has the highest TE score during the period studied; hence, technology transfers from the US to other countries in the Asia-Pacific region may be confirmed. Of course, technology appropriate to the capability of each country may be transferred. However, in high-tech industries such as telecommunications, a flexible modification of technology seems to be very difficult. This may lead to serious disparities between the TEs of different countries in the Asia-Pacific region. However, the gap between the TE values of some countries like Japan, Singapore, Korea, and the US has been closed over the period studied, and we can affirm that Telecommunications technology has been transferred to these countries effectively.

In addition, during the period studied, we observe a positive and common technological change all over the region. We can observe that common institutional and organizational changes in the Asia-Pacific region after the 1980s have improved efficiency in the telecommunications sector. Privatization in telecommunications industries may be considered as a crucial factor for such change. It can thus be considered that telecommunications industries have recently become over-competitive as a result of deregulation and rapid technological advancement. The estimation results reflect such recent market conditions in the industries in the Asia-Pacific region.

From the estimation of the panel data set, we can confirm that the differences between the TE values of countries are explained by per capita GDP and the fixed phone penetration rate. To raise the TE level in the telecommunications industry, it is important for developing countries to maintain their economic growth and raise the per capita GDP level. This result applies to countries with larger estimated parameters of the dummy variable, among those with per capita GDP below 20,000 US dollars. Additionally, the diffusion of fixed phones is important for the development of telecommunications industries in developing countries. Installation of fixed phone lines is one of the important premises for the provision of advanced telecommunication services—for example, the use of broadband and cloud computing. To raise the TE of the telecommunications industries in developing countries, it may be desirable to provide funds for the promotion of infrastructure relevant to fixed phone lines.

Acknowledgement

We are thankful for the research support of the KDDI Foundation (International Communications Foundation) and the comments from several anonymous referees.

REFERENCES

Battese, G. E., and T. J. Coelli (1995) "A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data," *Empirical Economics* Vol. 20(2), pp.325-332.

Battistoni, E., D. Campisi, and P. Mancuso (2006) "European Integration and Telecommunication Productivity Convergence," In Governance of Communication Networks: Connecting Societies and Markets with IT, eds. B. Preissl and J. Muller. Heidelberg: Physica-Verlag Heidelberg.

Coelli, T. J., D.S. P. Rao, C. J. O'Donnell, and G. E. Battese (2005), *An Introduction to Efficiency and Productivity Analysis* 2ed, Boston, MA: Springer Science + Business Media, Inc.

Cowhey, P., and M. Klimenko (2001) "The WTO Agreement and Telecommunications Policy Reform, "*World Bank Policy Research Working Paper*, No. 2601.

Erber, G. (2006) "Benchmarking Efficiency of Telecommunication Industries in the US and Major European Countries A Stochastic Possibility Frontiers Approach," *DIW Berlin Discussion Paper,* No. 621.

Helpman, E., ed. (1998), *General purpose technologies and economic growth*, Cambridge, MA: MIT Press.

ITU (2006), *World Telecommunication/ICT Development Report 2006: Measuring ICT for Social and Economic Development,* Geneva: International Telecommunication Union.

Kodde, D.A., and F.C. Palm (1986) "Wald Criteria for Jointly Testing Equality and Inequality Restrictions," *Econometrica*, Vol. 54 (5), pp.1243-1248.

Lee, S., (2008) "Market Liberalization and wnership Status of Incumbent Telecom Enterprises: Global Evidence from the Telecom Sector, "*Economics Bulletin*, Vol. 12(30), pp.1-10.

Nemoto, J., and S. Asai (2002), "Scale Economies, Technical Change and Productivity Growth in Japanese Local Telecommunications Service," *Japan and the World Economy*, Vol.14(3), pp.305-320.

Wallsten, S. (2003) "Of Carts and Horses: Regulation and Privatization in Telecommunications Reforms, " *Journal of Policy Reform*, Vol. 6(4), pp.217-231.

Wallsten, S. (2004) "Privatizing Monopolies in Developing Countries: The Real Effects of Exclusivity Periods in Telecommunications, "*Journal of Regulatory Economics*, Vol. 26(3), pp.303-320.