An International Comparison on Total Factor Productivity Changes in ICT Industry among US, Japan, Korea and Taiwan (1981-2010)

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I. Introduction
The total output value of ICT (information and communication technology) in the United States, Japan, Korea and Taiwan was USD 490.5 billion, 400 billion, 321.4 billion, and 240.5 billion respectively in 2009/2010.

Korea and Taiwan registered a remarkable annual growth rate of 16.7 percent and 12.8 percent respectively during 1981-2010 in ICT industry, while that of the United States and Japan was 7.5 percent and 6.1 percent respectively in the same period.

It is important to analyze the source of growth in ICT industry among the above four countries.

Korea and Taiwan seems to be catching up quickly with Japan and the United States in terms of total output value. Whether it is also true that Korea and Taiwan are also catching up Japan and the United States in the “technology gap” is worthy of study.
Purposes of this paper are:

1) To measure the TFP growth and analyze the sources of ICT growth in Taiwan during 1981-2010.
2) To compare the sources of growth and TFP growth of ICT industry among Taiwan, Korea, Japan and the United States.
3) To measure the “technology gap” of ICT industry among the above four countries during 1981-2010.

The methodology and data compilation employed is the same as World KLEMS and Asia KLEMS.
II. Methodology
Following the methodology of World KLEMS and Asia KLEMS, we measure sector-level productivity by using the translog production function:

$$
\ln Q = \alpha_0 + \alpha_T T + \alpha_K \ln K + \alpha_L \ln L + \alpha_E \ln E + \alpha_M \ln M \\
+ 1/2 \beta_{KK} (\ln K)^2 + \beta_{KL} \ln K \cdot \ln L + \beta_{KE} \ln K \cdot \ln E + \beta_{KM} \ln K \cdot \ln M + \beta_{KT} \ln KT \\
+ 1/2 \beta_{LL} (\ln L)^2 + \beta_{LE} \ln L \cdot \ln E + \beta_{KM} \ln K \cdot \ln M + \beta_{LT} \ln LT \\
+ 1/2 \beta_{EE} (\ln E)^2 + \beta_{EM} \ln E \cdot \ln M + \beta_{ET} \ln ET \\
+ 1/2 \beta_{MM} (\ln M)^2 + \beta_{LT} \ln MT + 1/2 \beta_{TT} T^2
$$

which is characterized by CRS if, and only if, the parameters satisfy the condition of coefficient characteristics.

7
In addition, for a well-behaved function the production should be satisfied by the concavity constraint. That is, that the Hessian’s matrix is negative semi-definite. Differentiating equation (1) with respect to $K$, $L$, $E$, $M$ and $T$, the value-share equations of capital, labor, energy and intermediate can be expressed as:

$$S_K = \alpha_K + \beta_{KK} \ln K + \beta_{KL} \ln L + \beta_{KE} \ln E + \beta_{KM} \ln M + \beta_{KT} T$$  \hspace{1cm} (2)$$

$$S_L = \alpha_L + \beta_{LK} \ln K + \beta_{LL} \ln L + \beta_{LE} \ln E + \beta_{LM} \ln M + \beta_{LT} T$$  \hspace{1cm} (3)$$

$$S_E = \alpha_E + \beta_{EK} \ln K + \beta_{EL} \ln L + \beta_{EE} \ln E + \beta_{EM} \ln M + \beta_{ET} T$$  \hspace{1cm} (4)$$

$$S_M = \alpha_M + \beta_{MK} \ln K + \beta_{ML} \ln L + \beta_{ME} \ln E + \beta_{MM} \ln M + \beta_{MT} T$$  \hspace{1cm} (5)$$

In addition, the rate of change in TFP can be shown as:

$$R_T = \alpha_T + \beta_{KT} \ln K + \beta_{LT} \ln L + \beta_{ET} \ln E + \beta_{MT} \ln M + \beta_{TT} T$$  \hspace{1cm} (6)$$
For the data at any two discrete points in time, say $T$ and $T-1$, the average rate of TFP change can be derived from growth accounting, i.e., the difference between successive logarithms of output less a weighted average of the differences between successive logarithms of capital, labor, energy and intermediate inputs with weights given based on average value shares:

$$
\overline{R_T} = \ln Q(T) - \ln Q(T-1) - \overline{s_K} [\ln K(T) - \ln K(T-1)] - \overline{s_L} [\ln L(T) - \ln L(T-1)]
- \overline{s_E} [\ln E(T) - \ln E(T-1)] - \overline{s_M} [\ln M(T) - \ln M(T-1)]
$$

(7)

$$
\overline{s_i} = 1/2 [s_i(T) + s_i(T-1)] \quad i = K, L, E, M
$$

(8)

$$
\overline{R_T} = 1/2 [R_T(T) + R_T(T-1)]
$$

(9)

The index of (7) is referred to as the Tornqvist index of TFP or the translog index of TFP.
III. Data Compilation
3.1 Data Compilation of Taiwan


- The data of factor input and output were compiled as follows:
3.1.1 Capital Input

Capital input can be decomposed into six categories:

- \((K_1)\) buildings
- \((K_2)\) other buildings
- \((K_3)\) transportation equipment
- \((K_4)\) machineries
- \((K_5)\) inventory
- \((K_6)\) land
Except for land, the time series capital stock in 1961-2010 is calculated by adding up the net capital formation, which is the difference between the gross capital formation and the depreciation, starting from 1951 - the beginning year of the *National Income Account* in Taiwan.

The gross capital formation during 1951-2010 comes from the DGBAS; the types of depreciation are compiled by employing the constant rate depreciation method and the asset lives listed in the *National Wealth Census*. 
This method implicitly assumes that no net capital stock existed before 1951. The time-series land data come from the *Industrial and Commercial Census* in every five-year by applying interpolation/extrapolation method.

We then used the data on various types of capital stock obtained from the *National Wealth Census* in 1988, DGBKAS as a reference to adjust the time-series capital stock aforementioned.
The types of capital service prices are compiled by using the following equation of Christensen-Jorgenson (1969, 1970):

\[ P_{ki} = \frac{1 - \mu(T) \cdot Z_i(T)}{1 - \mu(T)} \left[ P_{ii}(T - 1) \cdot (1 - \mu(T)) \cdot R_r(T) + \delta_i \cdot P_{ii}(T) - (P_{ii}(T) - P_{ii}(T - 1)) \right] \]

\[ + P_{ii}(T) \cdot \tau_i(T), \quad (i = 1, 2, 3, 4) \]

By using the constant rate of depreciation method, the present value of depreciation in relation to a dollar of investment good i is calculated by means of the following equations:

\[ \delta_i = 1 - \left( \frac{S_i}{C_i} \right)^{\frac{1}{N_i}} \quad (\text{given } S_i = 0.1C_i) \]

\[ Z_i(T) = \sum \left[ \frac{(1 - \delta_i)^{N_i - 1} \cdot \delta_i}{(1 + r)^{N_i}} \right] \]

The data on \( N_i \) and \( r \) come from the National Wealth Census (1988) and Financial Statistics Monthly, respectively.
The deflator in relation to capital $i$ is the quotient of the gross capital formation at current prices and the gross capital formation at constant 2011 prices. Both of these are provided by the Statistics Bureau of the DGBAS.

Based on the corresponding tax code, tax rates for property ($Z_i(T)$), buildings ($K_1$), and other buildings ($K_2$) are assumed to be 3.0 percent. That for land ($K_6$) is assumed to be 1.5 percent. No property tax is levied on machineries ($K_4$) and inventory ($K_5$). The property tax rate with regard to the transportation equipment ($K_3$) is calculated as:

The property tax rate with regard to the transportation equipment ($K_3$) is calculated as:

\[
K_3 = \frac{\text{The license revenue for mobile cars at current prices}}{\text{the value of the transportation equipment of all residents}}
\]
The internal rate of return \( (R_r(T)) \) is calculated by:

\[
R_r(T) = \frac{PC - \sum_{i=1}^{6} \left[ \frac{1 - \mu(T) \cdot Z_i(T)}{1 - \mu(T)} \cdot (\delta P_{ii}(T) - P_{ii}(T)) \right] \cdot K_i}{\sum_{i=1}^{6} (1 - \mu(T) \cdot Z_i(T)) \cdot P_{ii}(T - 1) \cdot K_i(T - 1)}
\]

Where PC denotes the property compensation, which is the sum of rent, interest and profit depreciation, and is equal to the summation of the products of \( K_i \) and \( P_k \):

\[
PC = \sum_{i=1}^{6} P_k \cdot K_i(T - 1)
\]

Since the production of unpaid workers tends to be omitted from the survey of National Income and Product Accounts, especially in agriculture or in the quarrying industries and so on, we adjust and calculate this value by using the Input-Output Table for various years (i.e. 1976, 1978, 1986, 1991, 1996, 2001, 2006, 2011).

We interpolate and extrapolate the input-output tables to obtain the time-series \( S_K \) and \( S_L \) for adjusting the \( S_K \) and \( S_L \) series obtained from the National Income Account.
3.1.2 Labor Input

72 categories of labor for each industry are classified on the basis of:

- **Sex**
  - (a) Male  (b) Female

- **Employment Status**
  - (a) Employed  (b) Self-employed and/or unpaid family worker

- **Age**
  - (a) 15-24  (b) 25-34  (c) 35-44  (d) 45-54  (e) 55-64  (f) over 65

- **Education**
  - (a) Junior high school graduate or less
  - (b) Senior or vocational high school graduate
  - (c) College graduate and above
Wages and labor inputs on the basis of 72 categories during 1981-2010 are compiled from the magnetic tape of the Manpower Survey, DGBAS; total employment is from Manpower Survey, DGBAS and wage comes from Labor product and Wage Monthly, DGBAS.

We further incorporate the data of working hour during 1981-2010 into the labor input estimation.
3.1.3 Energy Input

- Energy input consists of coal, oil products, natural gas, and electricity. We calculated the translog index of energy input.

- The quantities of energy consumed are available in Energy Balance in Taiwan, R.O.C., issued by the Energy Commission, MOEA.

- Cost shares of types of energy are calculated by using the energy consumption data mentioned above and the data on prices of types of energy. The price data of domestic coal come from Commodity Price Monthly DGBAS, and Import-Export Trade Monthly, MOF.

- The price of oil, LNG and electricity are sorting from CPC and Taipower Company.
3.1.4 Intermediate Input

- The intermediate inputs are split into five categories: agricultural, industrial, transportation, services and imports intermediate input.

- The value and value share of intermediate input as a whole comes from the National Income Account.

- Since the data on intermediate input in the National Income Account includes energy input, we subtract the value of energy input from the value of intermediate input.

- Furthermore, the intermediate input deflator of agricultural, industrial, transportation, and services is obtained from DGBAS and the imports intermediate input deflator is collected from Ministry of Finance.
3.1.5 Real Value Added and Total Output

- The time series for total output and value added at nominal prices during 1981-2010 come from the DGBAS.

- However, real total output and real value added of ICT industries are calculated by nominal total output and nominal value added (excluding tax) deflated with total output deflator and value added deflator respectively.

- The above two deflators are provided by DGBAS.
3.2 Data Compilation of Other countries

- The data of total output, capital input, labor input and intermediate input (including energy intermediate input and non-energy intermediate input), and growth rate of TFP in Japan, Korea and the United States are obtained from World KLEMS Database and Asia KLEMS Database.
- The relative TFP of ICT industries in 1995, which are employed to measure the “technology gap” among four countries come from Motohashi (2007).
IV. Empirical Results
4.1 The Growth Rate of Total Output in ICT Industries (1981-2010)

- According to the database of World KLEMS and Asia KLEMS, the total output value of ICT (information and communication technology) in the United States, Japan Korea and Taiwan was USD 490.5 billion, 400 billion, 321.4 billion, and 240.5 billion respectively in 2009/2010.

- Table 1 presents the international comparison on growth rate of total output (Q), various inputs and TFP. From Row 1, Table 1, the following important conclusions emerge:

  1. Korea had the highest growth rate in total output (Q) of 16.7 percent during 1981-2010 among four countries. Taiwan ranked next (12.8 percent), followed by the United States (7.5 percent) and Japan (6.1 percent). (see Row 1, Table 1)

  2. The United States’ growth rate had peaked since 1999. It dropped to -0.5 percent per annum during 2007-2010. (see Row 1, Table 1)

  3. Japan’s deceleration came even earlier. It started from 1990. It fell to -11.0 percent during 2007-2010. (see Row 1, Table 1)
4.2 The Growth Rate of Capital (K), Labor (L) and Intermediate Input (M) in ICT Industries during 1981-2010

From Row 2 to Row 4 of Table 1, we concluded that:

1. Taiwan had the highest growth rate of capital input (15.5 percent) during 1981-2010. The followings were Korea (13.2 percent), Japan (7.4 percent) and the United States (4.8 percent). (see Row 2, Table 1)

2. It is worth of noting that the capital input growth rate of the above four countries are fell sharply during 2007-2010. (see Row 2, Table 1)

3. Comparing with the growth of capital input, the labor input growth rate was lower in all countries. Taiwan was the highest country with an annual growth rate of 6.0 percent during 1981-2010, followed by Korea (3.9 percent), Japan (0.6 percent) and the United States (-1.2 percent). (see Row 3, Table 1)
4. It is noted that the labor input of Japan and the United States registered negative growth since 1999. The labor input of ICE decrease 2.0 percent per annum and 3.4 percent per annum respectively in Japan and the United States. (see Row 3, Table 1)

5. Compared with Japan and the United States, Korea had much higher growth rate in intermediate input during 1981-2010. Korea grew with a pace of 16.7 percent per annum in intermediate input, while Taiwan increased with 12.3 percent per annum. (see Row 4, Table 1)

6. In contrast, Japan and the United States’ intermediate input grew with a pace of 4.0 percent per annum and 1.3 percent per annum respectively during 1981-2010. (see Row 4, Table 1)

7. Compared with the growth rate of sub-periods, during the same period of 1981-2010, all of the countries decelerated in intermediate inputs growth except Korea. The annual growth rate of intermediate input in Taiwan decrease from 10.0 percent during 1981-1990 to 5.2 percent during 2007-2010. That of Japan and the United States sharply declined from 10.7 percent and 4.0 percent during 1981-1990 to -10.9 percent and -14.8 percent during 2007-2010. (see Row 4, Table 1)
4.3 The Sources of Total Output Growth Growth

Table 2 and Table 3 present the sources of total output growth and the relative contribution ratio of capital, labor and intermediate input to total output growth, respectively in ICT industries during 1981-2010. Table 3 is calibrated from Table 2. From Table 3, we concluded that:

1. The relative contribution ratio of capital input to total output growth during 1981-2010, Taiwan ranked the first (13.0 percent), while Japan (11.64 percent) ranked the second. Korea and the United States ranked the third (10.25 percent) and the fourth (7.57 percent) respectively. (see Row 2, Table 3)

2. The relative contribution ratio of labor input to total output growth during 1981-2010, all of the four countries were lower than 7.0 percent. Taiwan was 6.7 percent, Korea (3.0 percent), Japan (2.5 percent) and the United States (-5.0 percent). (see Row 3, Table 3)

3. The relative contribution ratio of intermediate input to total output was very high in Korea (74.06 percent) and Taiwan (72.87 percent) during 1981-2010. Conversely, that of Japan and the United States was 43.43 percent and 9.8 percent respectively. (see Row 4, Table 3)
4.4 The Growth Rate of TFP(1981-2010)

From Row 5 of Table 1 and Table 3, the following important conclusions emerge:

1. For the whole observation period (1981-2010), the United States had the highest TFP growth of 6.2 percent per annum, followed by Japan (2.4 percent) and Korea (2.0 percent) and Taiwan (0.8 percent). (see Row 5, Table 1)

2. Comparing with the growth rate of sub-periods, we found that TFP growth of the United States and Taiwan had accelerated. The annual TFP growth rate of the United States increased from 3.8 percent during 1981-1990 to 8.3 percent during 2007-2010, and that of Taiwan increased from -0.3 percent during 1981-1990 to 3.0 percent during 2007-2010. (see Row 5, Table 1)

3. In contrast, Japan and Korea had a trend of deceleration in the TFP growth. The annual TFP growth rate of Japan and Korea declined from 3.0 percent and 1.6 percent respectively during 1981-1990 to -2.3 percent and 1.1 percent respectively during 2007-2010. (see Row 5, Table 1)
4. During 1981-2010, the relative contribution ratio of TFP to total output growth was the greatest in the United States (87.9 percent), Japan ranked the second (42.4 percent), followed by Korea (13.1 percent) and Taiwan (7.4 percent). (see Row 5, Table 3)

5. However, the relative contribution ratio of TFP to total output increased in the United States and Taiwan, while it decreased in Korea and Japan. For example, the relative contribution ratio of TFP to total output growth in Taiwan increased from -2.2 percent during 1981-1990 to 41.9 percent during 2007-2010. (see Row 5, Table 3)

6. Due to various TFP growths among countries, the technology gap in ICT industry between the United States and the rest of three countries got wider during the whole observation period of 1995-2010 (see Figure 1).

7. And the technology gap in ICT industry between Japan, Korea and Taiwan got wider during 2003-2007 and gradually narrowed after 2008 (see Figure 1).

8. The technology gap in ICT industry between Korea and Taiwan got wider during 1995-2007 and gradually narrowed after 2008 (see Figure 1).
Table 1 An International Comparison on Growth Rate of Total Output, Capital, Labor, Intermediate Input and TFP by Countries, 1981-2010

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Source: Database of World KLEMS and Asia KLEMS, calculated by the article.
Table 2 The Sources of Total Output Growth by Countries, 1981-2010

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</tr>
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Unit: %

Source: Database of World KLEMS and Asia KLEMS, calculated by the article.
Table 3 The Relative Contribution Ratio of Capital, Labor, Intermediate Input and TFP to Total Output Growth by Countries, 1981-2010

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Unit: %

Source: Database of World KLEMS and Asia KLEMS, calculated by the article.
Figure 1 Trend of TFP Growth by Countries (1995-2010)

Source: Database of World KLEMS and Asia KLEMS, Motohashi (2007), calculated by the article.
4.4 TFP and the Value Added Ratio

Comparing to the United States and Japan, Taiwan and Korea had lower TFP level. It might lead to lower value added ratio in Taiwan and Korea.

The value added ratio of ICT industry in Taiwan and Korea was 20.55 percent and 22.7 percent respectively in 2010. In contrast, that of Japan and the United States was 34.53 percent and 62.98 percent respectively. (see Figure 2)
Figure 2 Value Added Ratio of ICT industry by Countries in 2010

Source: OECD.stat, calculated by this article.
Note: the value of Japan is 2009.
Why TFP of ICT industry is different among the United States, Japan, Korea and Taiwan is worthwhile of further study. According to Liang (2009), Taiwan’s TFP changes for the whole economy was affected by R&D, among the other factors such as infrastructure, exchange rate, industrial policy and so on. International comparison on R&D expense of ICT industry in total output is presented in Figure 3. From Figure 3, we found that lower R&D expense might provide a clue to lower TFP in Taiwan and Korea, compared to the United States and Japan. The R&D expense in total output of ICT industry in Taiwan and Korea was 2.81 percent and 4.42 percent respectively during 1987-2010. Conversely, that of the United States and Japan was 8.01 percent and 9.66 percent respectively.
Figure 3 Average R&D Expense in Total Output Value of ICT industry by Countries (1987-2010)

Source: OECD.stat, calculated by this article.
Note: the value of Japan is 1987-2009.
V. Conclusions
Conclusions

1. The annual growth rate of total output in Korea and Taiwan were 16.7 percent and 12.8 percent respectively during 1981-2010, while that of the United States and Japan was 7.5 percent and 6.1 percent respectively in the same year.

2. The growth rate of TFP of ICT industry in the United States, Japan, Korea and Taiwan were 6.2 percent, 2.4 percent, 2 percent and 0.8 percent per year respectively during 1981-2010 in ICT industry.
3. The relative contribution ratio of TFP of ICT industry in US, Japan, Korea and Taiwan were 87.9 percent, 42.4 percent, 13.1 percent and 7.4 percent respectively during 1981-2010 consequently, we concluded that US. and Japan were TFP-driven; while that of Korea and Taiwan were input-driven in ICT industry during 1981-2010.

4. It is worth noting that contrast with Korea, Taiwan’s relative contribution ratio of TFP accelerated during the latest period of 2007-2010, becoming the second largest contributor to total output growth.
5. The technology gap in ICT industry between the US and the rest of three countries got wider during 1995-2010.


8. Lower R&D expense in total output of ICT industry might provide clue to lower TFP growth in Taiwan and Korea, compared to that of the United States and Japan during 1981-2010.
Thank you for your attention!