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An International Comparison of the TFP Levels and the Productivity Convergence of Japanese, Korean, Taiwanese, and Chinese Listed Firms (Extended Version)

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Abstract

Focusing on Japanese, Korean, Taiwanese, and Chinese firms in the manufacturing sector, this paper examines productivity catch-up at the firm level using the distance from the technology frontier as a direct measure of the potential for catch-up. We also examine the role of absorptive capacity for technological catch-up by including variables such as R&D expenditure and foreign ownership in our empirical estimation.

We find that the national frontier has a stronger pull on domestic firms than the regional frontier, which is in line with findings by Bartelsman, Haskel and Martin (2008). This result indicates that policies to raise the technology level of national frontier firms are beneficial for all firms in that country.

Keywords: productivity; catch-up; absorptive capacity

JEL classification: D24, O47, O53

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1. Introduction

Recent empirical and theoretical studies on productivity suggest that high productivity in foreign countries tends to have a positive impact on domestic productivity and the catch-up towards the technology frontier. For example, Cameron, Proudman and Redding (2005), examining the role of technology transfer in productivity growth at the industry level in the United Kingdom since 1970, found that research and development (R&D) affects productivity growth through innovation, while international trade facilitates the transfer of technology. Meanwhile, Griffith, Redding and Van Reenen (2003, 2004) examined both theoretically and empirically the role of R&D in innovation, absorptive capacity, and convergence. Using a panel of industries across twelve OECD countries, they found evidence of positive R&D effects on both rates of innovation and technology transfer. Moreover, Kneller and Stevens (2006), empirically investigating whether absorptive capacity helps to explain cross-country differences in technical efficiency, found that absorptive capacity provides a useful explanation of differences in industrial productivity among OECD countries. They argue that human capital affects productivity both directly through improvements in efficiency and indirectly through enhancing absorptive capacity.

More recently, utilizing micro data, the divergence or convergence of productivity among firms has been intensively scrutinized, providing us with insights into the mechanisms underlying productivity convergence or divergence across countries. The large body of literature on micro-level productivity has shown that firms' managerial ability, use of technology, and human capital, as well as competitive pressure and technology diffusion or spillovers are important determinants of productivity levels and productivity growth.[1] On the other hand, empirical studies focusing on the connection between aggregate and micro productivity growth have examined the contribution of resource reallocation across firms to aggregate productivity growth, based on the idea that aggregate productivity grows faster if more inputs are allocated to firms with high productivity.

However, the number of micro-level productivity analyses from an international comparative perspective is very limited.[2] Most recent micro-level studies compare productivity levels or productivity growth within a country or examine whether non-frontier firms within the country are catching up with national frontier firms. Unfortunately, such studies on individual countries remain silent on whether productivity across countries is converging, since they cannot identify the global technology frontiers that can be regarded as sources of international knowledge spillovers. A small number of pioneering works on the international comparison of productivity and firm dynamics based on micro data do exist, such as Bartelsman, Scarpetta and Schivardi (2003) and Bartelsman, Haltiwanger and Scarpetta (2004, 2005), which attempt to explore the country-specific factors that affect aggregate patterns of productivity growth.

Although the coverage of the datasets of these studies differs across countries, the authors of these studies do manage to compile comprehensive firm-level data covering almost all firms in manufacturing and other industries in many developed countries. Unfortunately, however, Japan and China are not analyzed in these studies. Although Korea is included in the study by Bartelsman, Haltiwanger and Scarpetta (2004, 2005), no TFP analysis for Korea is conducted.

In this paper, focusing on Japanese, Korean, Taiwanese, and Chinese firms in the manufacturing sector, we examine productivity catch-up at the firm level using the distance from the national and the regional technology frontier. The reason for using the reginal technology frontier is that although most previous studies regard the United States as the global productivity leader, we do not have micro-data suitable for the measurement of the TFP of U.S. firms.[3] Hence, we assume that the average of the TFP of firms within the top hexadecimal (roughly top 6%) of the TFP distribution within the four countries by industry and by year represents the regional frontier.[4] We also examine the role of absorptive capacity in technological catch-up by including variables such as R&D expenditure and foreign ownership in our empirical estimation.

Our main results can be summarized as follows. First, although Japanese firms enjoy the highest average TFP level in many industries, their TFP growth has been relatively slow during the past two decades. On the other hand, Taiwanese and Korean firms have achieved quite high

TFP growth in certain industries and in one industry they have even surpassed – the TFP level of their Japanese counterparts. However, the average TFP level of Chinese firms is still much lower than that of Japanese, Korean and Taiwanese firms in many industries. Second, in Korea, the TFP levels of low-performing firms are approaching those of the national frontier firms at a more rapid pace than those in other countries. In addition, once they have reached the national frontier-level TFP, Korean firms continue catching up with the regional frontier. In contrast, Chinese firms are very slow in catching up. Third, in all four countries, the speed of convergence of firms far behind the national frontier is faster than that of firms close to the frontier.

Overall, we find that in the four countries, the national frontier has a stronger pull on domestic firms than the regional frontier. This finding is consistent with Bartelsman, Haskel and Martin’s (2008) result on the national and global frontier for other countries.

The remainder of this paper is organized as follows. Section 2 explains our data and our method for the international comparison of firm-level TFP in Japan, Korea, Taiwan and China. Section 3 discusses the econometric model and estimation procedures used for our empirical analysis. Section 4 then reports our results, while Section 5 concludes and makes suggestions for the future direction of international comparative studies on productivity growth and convergence.

2. Comparing Firm-Level TFP in Japan, Korea, Taiwan and China: Methodological Issues

2.1 Estimation of Firm-Level TFP within Each Country

As a first step, we estimate each firm's TFP level relative to the industry average TFP level in the country where this firm is located. We use the multilateral TFP index method developed by Good, Nadiri and Sickles (1997).[5] This method makes possible not only cross-sectional comparisons but also time-series comparisons of firm-level TFP. Suppose that the data cover a period from t=0 to T and t_0 ($0<t_0<T$) is the benchmark year. In this method, the TFP level of firm f in industry j of country m in year t, $TFP_{f,t,j,m}$ is calculated by

$$\ln TFP_{f,t,j,m} = (\ln Q_{f,t,j,m} - \overline{\ln Q_{t,j,m}}) - \sum_{i=1}^{n} \frac{1}{2}(S_{f,i,t,j,m} + \overline{S_{i,t,j,m}})(\ln X_{f,i,t,j,m} - \overline{\ln X_{i,t,j,m}}) \quad (1)$$

for $t=t_0$,

$$\begin{aligned} \ln TFP_{f,t,j,m} &= \left(\ln Q_{f,t,j,m} - \overline{\ln Q_{t,j,m}}\right) - \sum_{i=1}^{n} \frac{1}{2}\left(S_{f,i,t,j,m} + \overline{S_{i,t,j,m}}\right)\left(\ln X_{f,i,t,j,m} - \overline{\ln X_{i,t,j,m}}\right) \\ &+ \sum_{s=t_0+1}^{t}\left(\overline{\ln Q_{s,j,m}} - \overline{\ln Q_{s-1,j,m}}\right) - \sum_{s=t_0+1}^{t}\sum_{i=1}^{n} \frac{1}{2}\left(\overline{S_{i,s,j,m}} + \overline{S_{i,s-1,j,m}}\right)\left(\overline{\ln X_{i,s,j,m}} - \overline{\ln X_{i,s-1,j,m}}\right) \end{aligned} \quad (2)$$

for $t>t_0$, and

$$\begin{aligned} \ln TFP_{f,t,j,m} &= \left(\ln Q_{f,t,j,m} - \overline{\ln Q_{t,j,m}}\right) - \sum_{i=1}^{n} \frac{1}{2}\left(S_{f,i,t,j,m} + \overline{S_{i,t,j,m}}\right)\left(\ln X_{f,i,t,j,m} - \overline{\ln X_{i,t,j,m}}\right) \\ &- \sum_{s=t+1}^{t_0}\left(\overline{\ln Q_{s,j,m}} - \overline{\ln Q_{s-1,j,m}}\right) + \sum_{s=t+1}^{t_0}\sum_{i=1}^{n} \frac{1}{2}\left(\overline{S_{i,s,j,m}} + \overline{S_{i,s-1,j,m}}\right)\left(\overline{\ln X_{i,s,j,m}} - \overline{\ln X_{i,s-1,j,m}}\right) \end{aligned} \quad (3)$$

for $t<t_0$,

where $Q_{f,t,j,m}$ stands for the real output (real sales) of firm f in year t, and $X_{f,i,t,j,m}$ represents the real input of production factor i of firm f in year t. Since there are three types of production factor – capital, labor, and intermediate input – the n in the above equation is 3 in our case. $S_{f,i,t,j,m}$ is the cost share[6] of production factor i at firm f in year t. $\overline{\ln Q_{t,j,m}}$ denotes the arithmetic average of the log value of the output, in year t, of all firms in industry j of country m to which firm f belongs, while $\overline{\ln X_{i,t,j,m}}$ stands for the arithmetic average of the log value of the input of production factor i, in year t, of all firms in industry j of country m to which firm f belongs. Finally, $\overline{S_{i,t,j,m}}$ is the arithmetic average of the cost share of the input of production factor i, in year t, of all firms in industry j of country m to which firm f belongs.

We define a hypothetical (representative) firm for each year and for each industry whose input and output are calculated as geometric means of those for all firms in this industry. The first two terms on the right-hand side of each of the three equations denote the cross-sectional TFP index based on the Theil-Tornqvist specification for each firm, in each year, relative to the hypothetical firms. Since this cross-sectional TFP index is not comparable between t and t-1, we adjust the cross sectional TFP index with the growth rate of TFP for the hypothetical firms, which is expressed by the third and fourth terms in equations (2) and (3). In other words, the calculations compare the performance of a firm with that of the representative firm of the industry in the benchmark year.[7]

We construct the firm-level TFP measure using annual financial data for the period

1985-2005 for Japan, Taiwan, and Korea, and for the period 1999-2005 for China. Our data cover all sectors except finance and insurance. In the case of Japan, our data cover firms listed on the Tokyo Stock Exchange (first and second sections), JASDAQ, Hercules, and Mothers. In the case of Korea, our data cover firms listed on the Korea Exchange plus firms subject to Korea's compulsory audit system. We obtain data for Korean firms from the KIS (Korea Information Service) Database. In the case of China, our data cover firms listed on the Shanghai Stock Exchange and the Shenzhen Stock Exchange. In the case of Taiwan, our data cover firms listed on the Taiwan Stock Exchange.

Nominal output[8] and intermediate input are obtained from the financial statements of each firm.[9] The real values of output and intermediate input are obtained by deflating nominal values using the price index for each industry[10] in each country. In order to take account of different depreciation rates for different assets, we estimate three types of capital assets – structures, machinery, and vehicles – separately, using the perpetual inventory method for Japan and Korea. In the case of Taiwan and China, since such detailed information on assets is not available, we use total investment series for the estimation of the total capital stock of each firm. Since financial statements only provide the number of employees, the labor input of each firm was obtained by multiplying the number of employees by the average number of hours worked in each industry in each country.[11]

2.2 Purchasing Power Parities (PPPs) for Output and Input

In order to compare the TFP levels of firms across countries, we need to take account of differences in the price levels of output, intermediate input, and investment goods across countries. In other words, we need purchasing power parity (PPP) data in order to convert firms' output and input in the four countries into a common currency unit. In this study, we obtain PPP data for industry output from the results of International Comparison of Productivity Among Asian Countries (ICPA) Project conducted by the Research Institute of Economy, Trade and Industry (RIETI).[12] When comparing per capita GDP across countries, usually PPPs based on price information for the final expenditure side are used, such as the PPPs of the International Comparison Program (ICP). However, in order to compare TFP levels across countries, we need PPPs for domestic output and input, which are difficult to estimate from price information for the final expenditure side. Therefore, following the methodology of the ICOP (International Comparison of Output and Productivity) project at Groningen University, the ICPA project mainly uses information on the unit value of output in addition to final expenditure side price information.

The unit value of product s of industry j in country m, $uv_{s,j,m}$ is computed by dividing the value of output of the product, $o_{s,j,m}$, by the quantity, $q_{s,j,m}$, as shown below:

$$uv_{s,j,m} = \frac{o_{s,j,m}}{q_{s,j,m}} \tag{4}$$

The unit value ratio of product *s* for industry *j* between country *A* and country *B*, $UVR_{s,j,B,A}$ is obtained by making an international comparison of the unit prices of similar product items:

$$UVR_{s,j,B,A} = \frac{uv_{s,j,A}}{uv_{s,j,B}} \tag{5}$$

The *UVR* on an industry basis is derived from the *UVR* on a product basis as the weighted average using the share of each product in the total output of a particular industry as a weight. Thus, the *UVR* between country *A* and country *B* in industry *j* is calculated as follows:

$$UVR_{j,B,A} = \sum_{s=1}^{S_j} \omega_{s,j} UVR_{s,j,B,A} \tag{6}$$

where S_j denotes the number of products in industry *j*, while $\omega_{s,j}$ denotes the production weights of product *s* in industry *j*. Each weight is derived as the geometric average of the production share of product *s* in industry *i* of country *A* and that of country *B*.[13]

2.3 Methodology for International Comparison of Firms' TFP Level

In this subsection, we explain our methodology for comparing firm-level TFP across countries. The most straightforward way to compare the productivity of firms in the four countries is to convert the value of output, intermediate input, and capital assets into the same currency unit, for example the Japanese yen, in a certain year, and to pool the data of all listed firms in the same industry across the four countries and directly apply Good, Nadiri and Sickles' methodology, that is, measure each firm's TFP level by equations (1), (2) and (3). However, this time, variables with an upper bar denote the average value of all listed firms in the same industry across the four countries. For example, equation (2) now becomes

$$\begin{aligned}\ln TFP_{f,t,j,m} &= \left(\ln Q_{f,t,j,m} - \overline{\ln Q_{t,j}}\right) - \sum_{i=1}^{n} \frac{1}{2}\left(S_{f,i,t,j,m} + \overline{S_{i,t,j}}\right)\left(\ln X_{f,i,t,j,m} - \overline{\ln X_{i,t,j}}\right) \\ &+ \sum_{s=t_0+1}^{t}\left(\overline{\ln Q_{s,j}} - \overline{\ln Q_{s-1,j}}\right) - \sum_{s=t_0+1}^{t}\sum_{i=1}^{n}\frac{1}{2}\left(\overline{S_{i,s,j}} + \overline{S_{i,s-1,j}}\right)\left(\overline{\ln X_{i,s,j}} - \overline{\ln X_{i,s-1,j}}\right)\end{aligned} \quad (7)$$

We employ this approach and measure the internationally comparable TFP for firms in the four countries. For this measurement, we adopt the Japanese yen to express monetary values, converting local currency values into yen using the PPPs for year 2000. We choose the year 2000 as our benchmark year, and the PPPs for 2000 are estimated by taking account of inter-temporal changes in industry price deflators in each country between the ICPA's benchmark year, 1997, and our benchmark year, 2000. For output, we use production PPPs by industry to convert firms' output into yen. For intermediate input, we convert the ICPA's producer price PPP into purchaser price PPP utilizing information on distribution margins and differences between the prices for domestic inputs and imported inputs in each country from the *Asian International Input-Output Table 1995* prepared by the Institute of Developing Economies (IDE-JETRO).

For capital input PPPs, assets are divided into structures, machinery and vehicles. For structures, we use the production PPP for construction; for machinery, we use the simple average of the production PPP for the general machinery, electric machinery, and precision machinery industries; and for vehicles, we use the simple average of the output PPP for the motor vehicle and other transportation equipment industry.[14] Our estimation results of output, capital, and intermediate PPP by industry are shown in Table A1.

As for labor input, we take account of differences in working hours across industries and across countries but do not take account of differences in labor quality resulting from differences in educational attainment. At this point, we do not have sufficient information for estimating labor quality at the firm level in each country.

2.4 Results of the International Comparison of Firms' TFP Level

2.4.1 Comparison of Sectoral TFP Growth in Japan, Korea, Taiwan, and China[15]

Let us begin by looking at the results on the level and growth rate of the weighted average TFP in each country's manufacturing and non-manufacturing sectors (Table 1). As weights, we use the sales share of each firm. The table shows that TFP growth in Japan's manufacturing sector slowed down somewhat in the first half of the 1990s before accelerating again slightly in the second half of that decade, and then further accelerating in the early 2000s. In Korea, the

TFP growth rate in the manufacturing sector was negative in the latter half of the 1980s, turned positive in the early 1990s, and increased even further in the latter half of the 1990s. However, TFP growth in the 2000-2005 period then dropped below levels in the 1990s. Turning to Taiwan, the manufacturing sector here enjoyed very high TFP growth between 1985 and 2005 with the exception of the second half of the 1990s, when the Taiwanese economy was hit by the Asian financial crisis. As mentioned, data for China are available only from 1999, and we find that the TFP growth in China's manufacturing sector in the period 2000-2005 was very slow.

Turning to the non-manufacturing sector, in Japan, TFP growth tended to be slower than in the manufacturing sector until 2000. In 2000-2005, however, the TFP growth rate in Japan's non-manufacturing sector exceeded that in the manufacturing sector. In Korea, the non-manufacturing sector showed high TFP growth in the 1990s at rates that were substantially higher than those for the non-manufacturing sector in Taiwan and Japan, although this reversed in the early 2000s. In Taiwan the non-manufacturing sector showed strong TFP growth in 1985-2005, although in most sub-periods, growth was slower than in the manufacturing sector. Finally, in China, the non-manufacturing sector in 2000-2005 registered considerable negative growth, mainly because of the large decline in the TFP of the oil and gas extraction sector.

Insert Table 1 about here.

2.4.2. Comparison of the TFP Level of Listed Firms in Selected Industries in Japan, Korea, Taiwan, and China

Figures 1 through 5 show a comparison of the average TFP levels of firms in Japan, Korea, Taiwan, and China for five principal manufacturing industries: the chemical, primary metal, non-electrical machinery, electrical machinery, and motor vehicle industries.

In the chemical industry (including pharmaceuticals), the average TFP of Taiwanese firms increased very rapidly in the early 2000s and in 2005 caught up with the average TFP of Japanese firms (Figure 1). On the other hand, Korean firms' TFP growth in this industry was very slow during 1985-2000 and their TFP level remains low relative to that of their Japanese and Taiwanese counterparts. Finally, despite some growth in TFP in the early 2000s, the TFP level of Chinese firms in this industry remains far below that of Japanese and Taiwanese firms.

Insert Figure 1 about here.

In the primary metal industry (Figure 2), Taiwanese firms improved their TFP levels steadily over the estimation period and by 2003 had almost caught up with Japanese firms, although they fell back again slightly in the following years. Korean firms' TFP in this sector plummeted in the late 1980s and early 1990s and continues to lag considerably behind the TFP levels of Japanese and Taiwanese firms. Meanwhile, the TFP level of firms in China did not improve much during the early 2000s, remaining low relative to the level in other three countries.

Insert Figure 2 about here.

In the non-electrical machinery industry (Figure 3), Taiwanese firms' TFP has grown rapidly and the average TFP level exceeds that of Japanese and Korean firms since the early 2000s. The TFP levels of Chinese machinery firms remain very low relative to those of their Japanese, Korean and Taiwanese counterparts.

Insert Figure 3 about here.

In the electrical machinery (Figure 4), all four countries experienced steady improvements in TFP levels in 1985-2005. While the TFP levels of Korean, Chinese, and Taiwanese firms were almost level in 2000, firms from China and Taiwan subsequently registered faster TFP growth than Korean firms, so that in 2005, the average TFP level of

Korean firms was lower than that of firms in Japan, Taiwan, and even China.

Insert Figure 4 about here.

Finally, in the motor vehicle industry (Figure 5), the TFP level of Japanese firms continues to be considerably higher than that of Korean, Taiwanese, and Chinese firms, although TFP levels in the latter three countries improved greatly in the early 2000s.

Insert Figure 5 about here.

3. Examining TFP Catch-Up: Econometric Model and Estimation Procedures

3.1. Econometric Model

In this section, we present the econometric model we use for our analysis of the catch-up process in East Asia. In our econometric analysis of catch-up, we focus on Japanese, Korean, Taiwanese, and Chinese firms in the manufacturing sector.

Following Bartelsman, Haskel, and Martin (2008), we estimate the speed of convergence to the productivity frontier. Like them, we assume that the growth rate of the knowledge capital of firm f, ΔA_f, is determined by the following equation:

$$\Delta \ln A_f = \alpha_1 \ln X_f + \alpha_{2,N} \ln\left(\frac{A_N}{A_f}\right) + \alpha_{2,G} \ln\left(\frac{A_G}{A_f}\right) \quad (8)$$

where X_f denotes this firm's input in the process of accumulating knowledge capital. We use firm *f*'s TFP level as a proxy for this firm's knowledge capital stock level, A_f. As the dependent variable, we use the one-year (log value) growth rate of each firm's TFP level. Since the TFP levels of some firms are implausibly high or low, we trimmed the upper and lower 2.5% of observations for each country and each manufacturing industry.[16]

The second and third terms on the right-hand side respectively denote the spillover effects from a country's own national technology frontier and from the regional technology frontier. For each year, country, and industry, we divide all firms into four groups based on their TFP level for each year, and use the average TFP levels of the top groups as that country's national frontier in that year in that industry. As for the regional frontier, for each industry, we pooled all firms in the four countries, divided these firms into sixteen groups according to their TFP level, and defined the regional frontier as the average TFP level of the top group firms.[17] This means that if the TFP levels of firms from, say, country *C* are all much higher than those of firms from other countries and if the number of firms in each country is the same, then the top group of the sixteen groups of the pooled firms becomes identical with the top group of the four groups in country *C*.

The distance of each firm to the national or regional frontier is measured as the difference between the firm's TFP level and the average TFP for the national or regional top group firms.[18] A_N denotes the average TFP level of the top quartile of firms in the country where firm f is located, and A_G denotes the average TFP level of the top hexadecimal firms in the four countries. If intra-national and international technology spillover effects are larger for firms with a low TFP level,[19] $\alpha_{2,N}$ and $\alpha_{2,G}$ will take positive values.

In the case of the regressions using pooled data for all four countries, the only proxy for firms' investment in knowledge capital, X_f, we can use is firm age. Firm age is measured as the difference between the establishment year and the current year. As for Chinese firms, since information on the year of establishment is not available, the difference between the year of listing and the current year is used. In the case of the country specific regressions, we can also take account of many other firm-specific variables which might influence firms' accumulation of knowledge capital or spillover effects from frontier firms. We will explain these additional data later.

In addition to firm age and distance to the national and regional technology frontiers, we include the growth potential of the industry to control for industry characteristics. The growth potential is measured as the average growth rate of the national frontier (*GNfrontier*) and the regional frontier (*GAfrontier*). In order to take account of industry-specific factors of TFP growth, we also add industry dummies to all our estimations.

To take account of the possibility of non-linear effects of the distance to the technology frontiers, we also estimate the following equation:

$$\Delta \ln A_f = \alpha_1 \ln X_f + \alpha_{2,N}{}^1 \ln\left(\frac{A_N}{A_f}\right) + \alpha_{2,N}{}^2 \left(\ln\left(\frac{A_N}{A_f}\right)\right)^2 + \alpha_{2,G}{}^1 \ln\left(\frac{A_G}{A_f}\right) + \alpha_{2,G}{}^2 \left(\ln\left(\frac{A_G}{A_f}\right)\right)^2 \tag{9}$$

In order to take account of additional firm-specific characteristics, which might influence firms' knowledge capital accumulation or spillover effects from frontier firms, we include additional variables such as firms' R&D intensity (data are available only for Korean and Japanese firms), foreign ownership share (data are available only for Chinese, Korean, and Japanese firms), and export ratio, as well as dummies for firms belonging to a corporate group (data are available only for Korean firms) and dummies for firms located in a coastal region (data are available only for Chinese firms). Since these data are not available for all four countries, when using these variables, we only run separate country-specific regressions for China, Korea, and Japan. Specifically, we estimate the following equation:

$$\begin{aligned}\Delta \ln A_f = &\sum_j \alpha_{1,j} \ln X_{f,j} + \alpha_{2,N} \ln\left(\frac{A_N}{A_f}\right) + \alpha_{2,G} \ln\left(\frac{A_G}{A_f}\right) \\ &+ \sum_j \alpha_{3,j}\left(\ln X_{f,j} \ln\left(\frac{A_N}{A_f}\right)\right) + \sum_j \alpha_{4,j}\left(\ln X_{f,j} \ln\left(\frac{A_G}{A_f}\right)\right)\end{aligned} \tag{10}$$

where ($X_{f,1}$, $X_{f,2}$, …., $X_{f,J}$) is a vector of the variables representing firm characteristics just mentioned. Specifically, the variables are defined and measured as follows. For Korea and Japan, we include R&D intensity, defined as the ratio of R&D expenditure over sales, in the estimation. We assume that firms which do not report R&D expenditure do not conduct R&D. In the estimations for China, Korea and Japan, we include a variable measuring the foreign ownership share, which is the ratio of the number of shares owned by foreigners to the total number of shares issued. This information is not available for Taiwan. Since the foreign ownership share is available only for listed firms, our estimation of equation (10) does not include Korean unlisted firms. In the case of Korean firms, we also prepare two additional variables, the export ratio and a business group dummy. The export ratio is defined as the ratio of the total value of exports over sales. We also assume that firms not reporting exports do not export.[20] The business group dummy takes a value of 1 when a firm is an affiliate of one of the top 30 business groups in Korea and a value of 0 otherwise. Finally, in the estimation for China, we include a dummy variable which takes a value of 1 when a firm is located in a coastal region and 0 otherwise.

As explanatory variables we also use products of the above variables with both the distance to the national frontier and the distance to the regional frontier.

4. Estimation Results

We now turn to our estimation results for the various equations. We start with the results for equation (8), which are shown in Table 3. Here, we only include firms' age as a proxy for accumulated knowledge. Column 1 shows the results for the complete sample of firms from all four countries. In the Table, *Ndist* denotes distance from the national frontier, $\ln(A_N/A_f)$, and *Adist* denotes distance from the regional frontier (in our estimation, the top group firms in the four countries), $\ln(A_G/A_f)$. In the case of the complete sample regression, we added country dummies.

The results suggest that the marginal pull from the national frontier is 0.277 and that from the regional frontier 0.006. In order to examine whether the pull from the national and the regional frontier is different across countries, we estimate equation (8) for each country separately. The results are shown in columns (2), (3), (4) and (5). They show that the marginal impact of the national frontier is largest for Korean firms, followed by that for Taiwanese, Chinese, and then Japanese firms. This result suggests that the speed of convergence to the national frontier is weak for Chinese and Japanese firms. Looking at the marginal impact of the regional technology frontier on Korean, Chinese, and Taiwanese firms' TFP growth (columns (2), (4), and (5)), we find for Korean firms, this is much smaller than the marginal impact of the national frontier (0.025 and 0.294, respectively), but both impacts are statistically significant. These results indicate that Korean firms are catching up not only to the national frontier but also to the regional frontier. In the case of Chinese and Taiwanese firms, the marginal impact of the regional frontier is also smaller than that of the national frontiers and is statistically insignificant.

Table 4 shows our estimation results for equation (9), which allows for non-linear effects of the distance to the national and regional frontiers, *Ndist* and *Adist*, by adding squared terms of these distances. When we take account of the possibility of non-linear effects of the distance to the technology frontiers, our main results, that is, that the marginal pull from the national frontier is larger than that from the regional frontier, do not change. We also find that, as column (1) shows, the marginal effect of distance to the national frontier is an increasing function of distance.

Table 5 shows our estimation results for equation (10) which includes a number of variables on firm characteristics which might influence firms' accumulation of knowledge capital or spillover effects from frontier firms, such as R&D intensity, export ratio, etc., as well as cross-terms of these variables and distance to the technology frontiers to capture the effect of absorptive capacity on catching up to the technology frontier. The result for Chinese firms are shown in column (1) and indicate that coastal location has a significant positive impact on TFP growth while foreign ownership does not. Both the cross-term of the coastal location dummy and the distance to the regional technology frontier and the cross term of the foreign ownership ratio and the distance to the regional technology frontier are not statistically significant. Finally, firms' age has a positive impact on the catch-up to the regional technology frontier.

Next, column (2) shows the results for Korean firms. Being part of a corporate group is associated with catching up to the regional technology frontier, but not the national frontier. Moreover, firms' age has a positive impact on TFP growth, but a negative impact on the effect of the distance to the national technology frontier.

Turning to the estimation for Japan in column (3), none of the variables related to distance to the regional frontier are statistically significant. The reason probably is that many of the Japanese top firms are also top firms in the four countries as a whole. Therefore, our measure of the distance to regional frontier is not appropriate for an examination of the catching-up process of Japanese firms to the global technology frontier. To analyze the issues addressed here for Japanese firms, we need more data for developed economies such the United States and European countries.

Insert Tables 2, 3, 4, and 5 about here.

5. Concluding Remarks and Implications for Future Research

Using firm-level data, this paper investigated the pattern of productivity convergence among firms from Japan, China, Taiwan, and Korea.

Our convergence analysis revealed that the pull from the national frontier is stronger in the case of Korea than that of Taiwan, China, and Japan. Our estimates based on the data for all four countries showed that lower-TFP firms were catching up to the national frontier at a faster speed than higher-TFP firms, providing evidence of strong convergence toward the national frontier.

Korean firms were also catching up toward the regional frontier. In addition, being part of a corporate group contributes to catching up to the regional frontier, but not to the national frontier. In China, firms located in the coastal regions tended to have higher TFP growth. We also find that firms' age has a positive impact on Chinese firms' catch-up to the regional frontier.

Overall, we found that the national frontier has a stronger pull on domestic firms than the regional frontier, a finding that is in line with that obtained by Bartelsman, Haskel, and Martin (2008). These results indicate that policies designed to raise the technology level of national frontier firms is beneficial for all domestic firms.

Because of data limitation, we were not able to examine East Asian firms' catch-up to frontier firms in the United States and the European Union. A comparison of the performance and/or competition between Asian frontier firms and frontier firms in non-Asian developed countries would be an interesting future research topic.

The mechanism of productivity convergence to frontier firms within a country and across countries is an issue that deserves further attention and more rigorous empirical analysis.

Although the compilation of international micro data is not an easy task, the development of internationally comparable micro data could shed more light on the growth mechanisms underlying the so-called “East Asian economic miracle,” as well as the determinants and consequences of heterogeneity among firms.

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Notes

[1] For a comprehensive literature survey on this issue, see Bartelsman and Doms (2000).

[2] In contrast, there have been extensive international productivity comparisons at the industry or macro level, conducted by the EU KLEMS project (see http://www.euklems.net) and at the Groningen Growth and Development Centre at the Economics Department of the University of Groningen (see http://www.ggdc.net).

[3] Including U.S. firms presents serious difficulties. First, labor cost data for U.S. firms are not available, so that we cannot estimate TFP indices for them. In addition, since unconsolidated financial statements are not available for U.S. firms, we cannot compare the input and output of U.S. firms with those of firms from the four countries considered here. Consolidated financial statements would not be suitable for this study, because they include the activities of overseas subsidiaries.

[4] As described below, this gives rise to the possibility of endogeneity problems, since the national frontier and the regional frontier defined in this paper is not exogenous. However, data limitations force us to use these endogenously defined national and global frontiers.

[5] It should be noted that while Good, Nadiri, and Sickles (1997) use an equation that accounts for changes in the composition of items for sale due to business diversification, we conducted the TFP estimation based on the assumption that firms produce only manufactured goods of the industry to which they belong.

[6] See Fukao, Inui, Ito, Kim, and Yuan (2009) for a detailed explanation of the method of estimating the firm-level cost share of each production factor.

[7] Here, we measure TFP using the index method. This method is not robust to scale economies and mark-ups. As an alternative, it is also possible to estimate TFP by employing the production function method. In this case, the methods that should be employed are those developed by Olley and Pakes (1996) or Levinsohn and Petrin (2003) to take into account simultaneity issues. However, these methods do not take into account heterogeneity in production functions across firms.

[8] Output is based on sales after adjusting for increases/decreases in inventories. For wholesalers and retailers, instead of sales, the difference between sales and purchases was used as output.

[9] We calculate firms' real output by deflating their nominal sales by the price index for the industry they operate in and then estimate firms' TFP using this real output. This is called the revenue TFP (TFPR). A potential problem with this method is that, as pointed out by Foster, Haltiwanger, and Syverson (2008: p. 400), "producers can have high TFPR levels because they are efficient, but this can also be driven by high producer-specific demand."

[10] Following the industry classification of the PPP data of the ICPA project, we reclassified each firm into one of 33 industries, using industry classification information on firms in the stock market where the firm is listed.

[11] See Fukao, Inui, Ito, Kim, and Yuan (2008) for more details on our firm level data.

[12] See Motohashi (2007) for details on the ICPA project.

[13] See Timmer and Ypma (2007) for a detailed explanation of the estimation method of PPPs in the ICPA project.

[14] Since we have no information on the asset composition of the capital stock of Taiwanese and Chinese firms, we use the share of each capital asset in each industry in Japan for each corresponding industry in Taiwan or China. The information on the capital asset composition in Japan was obtained from the Japan Industry Productivity Database 2008.

[15] TFP growth in the manufacturing and the non-manufacturing sector is calculated as the average of firms' TFP growth weighted by their output share in their respective sector.

[16] Summary statistics for, and the distribution of, observations used in our regressions are shown in Tables A2 and A3, respectively.

[17] Defining the technology frontiers in this way poses various problems. One of these is the problem of endogeneity. Strictly speaking, our national and regional frontier variables are endogenous in our regression equation. Instead, we should estimate the global technology frontier using data on firms from the United States and European Union and use this as an exogenous variable in our regression. However, the lack of appropriate data means that at present this is not possible. This is an issue we would like to leave for future research.

[18] An alternative approach to measuring distance from the technology frontier would be to use the productivity gap of a firm to the firm with the highest productivity (the frontier firm). However, doing so would mean that the measure is highly susceptible to temporary shocks and measurement errors with regard to the productivity of such frontier firms. For this reason, we decided to define the technology frontier as the average of the productivity of the top hexadecimal firms.

[19] Whether low-productivity firms can benefit from the "advantages of backwardness" depends on patterns of consumption and on the existence of a threshold level of infrastructural development (Dowrick and Gemmell 1991, Hall and Jones 1999, Barro and Sala-i-Martin 2004).

[20] Since reporting on R&D and exports in surveys in Japan and Korea is not compulsory, these variables may include serious measurement errors.

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Table 1. TFP Growth Rate (percent per annum)

		1985-90	1990-95	1995-00	2000-05
Japan	Manufacturing	0.95	0.71	0.93	1.76
	Non-manufacturing	0.50	-0.44	0.70	2.12
Korea	Manufacturing	-1.19	1.34	3.02	1.00
	Non-manufacturing	-2.32	3.37	5.01	0.57
Taiwan	Manufacturing	2.85	3.00	0.18	5.01
	Non-manufacturing	2.80	0.95	1.11	3.88
China	Manufacturing				0.08
	Non-manufacturing				-3.34

Source: Authors' calculations.

Table 2. Definitions of Variables

Variable	Definition
g1lnTFP	One-year growth rate of TFP from the current period to the next period
Ndist	Log distance of the TFP level from the national frontier
Adist	Log distance of the TFP level from the regional frontier
GNfrontier	One-year growth rate of the national frontier
GAfrontier	One-year growth rate of the regional frontier
Foreign ownership	Ratio of shares owned by foreigners
Dcoast	Dummy variable denoting whether the firm is located in one of China's coastal regions
Export ratio	Ratio of exports to gross sales
R&Di	R&D-sales ratio
Dgroup	Dummy variable denoting whether the firm is an affiliate of one of the top 30 business groups in Korea
Age	Firm age

Table 3. Estimation Result 1

	Pooled (1)		China (2)		Japan (3)		Korea (4)		Taiwan (5)	
Ndist	0.277	***	0.203	***	0.132	***	0.294	***	0.243	***
	(0.005)		(0.076)		(0.010)		(0.011)		(0.025)	
Adist	0.006	**	0.010		-0.015	*	0.025	***	0.037	
	(0.002)		(0.074)		(0.008)		(0.009)		(0.023)	
GNfrontier	0.83700	***	0.45100	***	0.49800	***	0.75400	***	0.54700	***
	(0.011)		(0.072)		(0.022)		(0.019)		(0.035)	
GAfrontier	-0.170	***	-0.021		-0.056	***	-0.150	***	0.081	
	(0.014)		(0.122)		(0.011)		(0.020)		(0.053)	
Age	-0.0002	***	0.0009		0.0000		-0.0003	***	-0.0013	***
	(0.000)		(0.001)		(0.000)		(0.000)		(0.000)	
D_China	-0.039	***								
	(0.002)									
D_Korea	-0.015	***								
	(0.001)									
D_Taiwan	-0.019	***								
	(0.001)									
R-squared	0.314		0.143		0.273		0.372		0.263	
Observations	78,406		3,462		22,981		42,846		9,117	

Note 1. ***p<0.01, **p<0.05, *p<0.1.

Note 2. Industry dummies and year dummies are included, but not reported.

Table 4. Estimation Result 2

	Pooled (1)	China (2)	Japan (3)	Korea (4)	Taiwan (5)
Ndist	0.202 ***	0.098	0.076 ***	0.244 ***	0.126 ***
	(0.010)	(0.090)	(0.023)	(0.016)	(0.037)
$Ndist^2$	0.171 ***	0.175 *	0.313 ***	0.127 ***	0.250 ***
	(0.029)	(0.102)	(0.095)	(0.035)	(0.080)
Adist	-0.034 ***	-0.015	-0.035 **	0.007	0.067
	(0.007)	(0.093)	(0.014)	(0.017)	(0.052)
$Adist^2$	0.043 ***	0.026	0.044 *	0.013	-0.025
	(0.008)	(0.055)	(0.024)	(0.014)	(0.055)
GNfrontier	0.833 ***	0.445 ***	0.515 ***	0.757 ***	0.535 ***
	(0.011)	(0.072)	(0.022)	(0.019)	(0.035)
GAfrontier	-0.169 ***	-0.021	-0.056 ***	-0.152 ***	0.123 **
	(0.014)	(0.118)	(0.011)	(0.020)	(0.053)
Age	-0.001 ***	0.003	0.000	-0.001 ***	-0.005 ***
	(0.000)	(0.002)	(0.000)	(0.000)	(0.001)
Age^2	0.000004 ***	-0.000256	-0.000001	0.000026 ***	0.000287 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
D_China	-0.042 ***				
	(0.003)				
D_Korea	-0.012 ***				
	(0.001)				
D_Taiwan	-0.019 ***				
	(0.002)				
R-squared	0.320	0.150	0.281	0.375	0.272
Observations	78,406	3,462	22,981	42,846	9,117

Note 1. ***p<0.01, **p<0.05, *p<0.1.

Note 2. Industry dummies and year dummies are included, but not reported.

Table 5. Estimation Result 3

	China (1)	Korea (2)	Japan (3)
Ndist	0.266 ***	0.283 *	0.146 ***
	(0.092)	(0.152)	(0.033)
Adist	-0.053	0.139	-0.029
	(0.083)	(0.145)	(0.021)
GNfrontier	0.4820 ***	0.8100 ***	0.4970 ***
	(0.083)	(0.131)	(0.022)
GAfrontier	-0.0114	-0.2020	-0.0562 ***
	(0.138)	(0.153)	(0.011)
Age	0.0007	0.0016 **	0.0001
	(0.004)	(0.001)	(0.000)
Age^2	-0.000469	-0.000016	-0.000001
	(0.000)	(0.000)	(0.000)
Dcoast	0.029 **		
	(0.012)		
Foreign ownership	-0.051	0.003	0.015
	(0.077)	(0.014)	(0.010)
R&Di		0.201	-0.048
		(0.547)	(0.054)
Export ratio		0.029	
		(0.025)	
Dgroup		0.008	
		(0.016)	
Ndist×Age	-0.0069	-0.0042 *	-0.0005
	(0.012)	(0.003)	(0.001)
Ndist×Dcoast	-0.030		
	(0.055)		
Ndist×Foreign	0.097		-0.164 **
	(0.307)		(0.077)
Ndist×R&Di		0.343	0.725
		(0.944)	(0.482)
Ndist×Export		0.114	
		(0.106)	
Ndist×Group		-0.190 *	
		(0.115)	
Adist×Age	0.0095 *	-0.0003	0.0002
	(0.005)	(0.001)	(0.000)
Adist×Dcoast	-0.010		
	(0.021)		
Adist×Foreign	0.065		0.038
	(0.124)		(0.030)
Adist×R&Di		-0.663	0.170
		(1.158)	(0.323)
Adist×Export		-0.101 *	
		(0.060)	
Adist×Dgroup		0.061 *	
		(0.037)	
R-squared	0.150	0.228	0.278
Observations	2,816	1,601	22,981

Note 1. ***p<0.01, **p<0.05, *p<0.1.

Note 2. Industry dummies and year dummies are included, but not reported.

Appendix

Table A1. Relative Output, Capital, and Intermediate Input Prices (2000, Japan=1)

	Relative Output Price			Relative Capital Price			Relative Intermediate Price		
	China	Korea	Taiwan	China	Korea	Taiwan	China	Korea	Taiwan
1 Agriculture	0.10	0.49	0.33	0.23	0.42	0.30	0.22	0.49	0.39
2 Coal mining	0.09	0.37	0.97	0.31	0.48	0.38	0.28	0.07	0.47
3 Metal and non-metallic mining	0.20	0.93	0.83	0.31	0.48	0.38	0.28	0.49	0.45
4 Oil and gas extraction	0.55	0.41	0.92	0.31	0.48	0.38	0.29	0.28	0.52
5 Construction	0.23	0.38	0.26	0.35	0.50	0.43	0.31	0.46	0.50
6 Food and kindred products	0.16	0.50	0.37	0.35	0.47	0.38	0.18	0.61	0.43
7 Textile mill products	0.39	0.64	0.54	0.32	0.43	0.36	0.40	0.57	0.51
8 Apparel	0.31	0.79	0.56	0.34	0.43	0.36	0.38	0.52	0.49
9 Lumber and wood products	0.27	0.38	0.33	0.33	0.47	0.39	0.25	0.35	0.38
10 Furniture and fixtures	0.47	0.42	0.54	0.33	0.41	0.38	0.31	0.49	0.48
11 Paper and allied products	0.35	0.76	0.61	0.34	0.38	0.37	0.34	0.64	0.60
12 Printing, publishing, and allied products	0.33	0.62	0.43	0.39	0.39	0.40	0.33	0.56	0.52
13 Chemicals	0.44	0.59	0.49	0.32	0.46	0.37	0.34	0.55	0.54
14 Petroleum and coal products	0.31	0.42	0.32	0.31	0.45	0.36	0.66	0.69	0.75
15 Leather	0.11	0.44	0.32	0.36	0.44	0.39	0.32	0.50	0.48
16 Stone, clay, and glass products	0.45	0.53	0.57	0.30	0.46	0.37	0.29	0.47	0.56
17 Primary metal	0.51	0.81	0.65	0.29	0.46	0.35	0.43	0.65	0.59
18 Fabricated metal	0.36	0.49	0.53	0.29	0.44	0.35	0.38	0.59	0.54
19 Non-electrical machinery	0.47	0.47	0.41	0.35	0.46	0.40	0.39	0.53	0.53
20 Electrical and electronic machinery	0.46	0.65	0.68	0.34	0.47	0.40	0.41	0.45	0.59
21 Motor vehicles	0.66	0.79	1.02	0.35	0.40	0.36	0.51	0.70	0.74
22 Transportation equipment and ordnance	0.51	0.53	0.78	0.34	0.42	0.38	0.44	0.53	0.66
23 Instruments	0.48	0.83	0.72	0.36	0.47	0.41	0.38	0.57	0.55
24 Rubber and miscellaneous plastics	0.25	0.64	0.75	0.35	0.41	0.37	0.36	0.55	0.55
25 Miscellaneous manufacturing	0.38	0.59	0.55	0.36	0.43	0.40	0.31	0.47	0.46
26 Transportation	0.24	0.43	0.81	0.28	0.44	0.35	0.32	0.51	0.51
27 Communications	0.48	0.67	0.33	0.30	0.48	0.38	0.22	0.50	0.37
28 Electricity utilities	0.28	0.50	0.50	0.26	0.45	0.34	0.30	0.54	0.59
29 Gas utilities	0.19	1.22	2.17	0.23	0.40	0.28	0.30	0.53	0.62
30 Trade	0.08	0.58	0.44	0.28	0.40	0.35	0.25	0.35	0.38
31 Finance, insurance, and real estate	0.31	0.46	0.24	0.25	0.37	0.29	0.25	0.42	0.31
32 Other private services	0.03	0.21	0.25	0.31	0.42	0.39	0.26	0.36	0.37
33 Public services	0.13	0.36	0.91	0.29	0.43	0.36	0.28	0.50	0.46

Source: Authors' calculations.

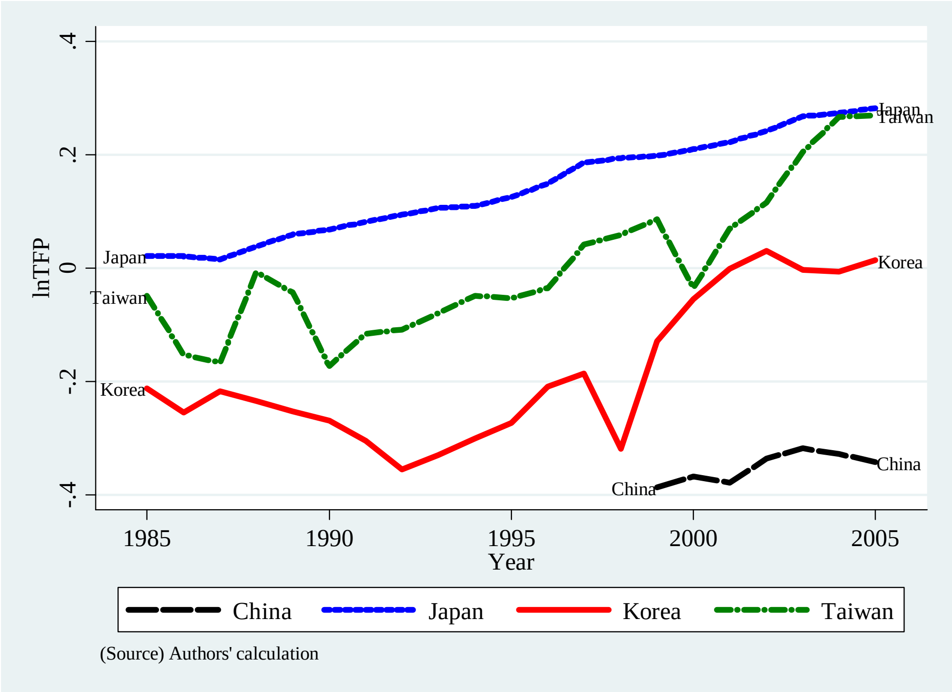
Table A2. Summary Statistics

Variable	N	mean	sd	min	p25	p50	p75	max
Whole sample								
g1lnTFP	78,412	0.016	0.089	-0.959	-0.022	0.013	0.052	0.965
Ndist	78,412	0.139	0.112	-0.458	0.069	0.126	0.191	1.150
Adist	78,412	0.383	0.232	-0.290	0.194	0.363	0.540	1.658
GAfrontier	78,412	0.013	0.034	-0.295	-0.005	0.010	0.032	0.339
GNfrontier	78,406	0.014	0.039	-0.312	-0.005	0.013	0.032	0.366
Age	78,412	23.793	21.931	0	6	15	39	117
China								
g1lnTFP	3,468	0.005	0.116	-0.959	-0.042	0.009	0.056	0.812
Ndist	3,468	0.187	0.155	-0.376	0.083	0.170	0.263	1.150
Adist	3,468	0.593	0.262	-0.194	0.410	0.597	0.783	1.658
GNfrontier	3,462	0.010	0.045	-0.218	-0.017	0.011	0.035	0.216
Age	3,468	4.352	2.872	0	2	4	6	12
Dcoast	2,866	0.506	0.500	0	0	1	1	1
Foreign ownership	2,828	0.013	0.055	0.000	0.000	0.000	0.000	0.558
Korea								
g1lnTFP	42,846	0.018	0.103	-0.763	-0.033	0.015	0.065	0.806
Ndist	42,846	0.151	0.117	-0.458	0.076	0.138	0.208	0.968
Adist	42,846	0.481	0.204	-0.107	0.338	0.469	0.611	1.603
GNfrontier	42,846	0.012	0.042	-0.295	-0.010	0.012	0.030	0.366
Age	42,846	13.938	10.125	0	6	12	20	73
Foreign ownership	1,601	0.081	0.129	0.0001	0.0023	0.0202	0.1072	0.9335
Dgroup	42,846	0.023	0.150	0	0	0	0	1
Export ratio	42,846	0.180	4.469	0.000	0.000	0.000	0.125	734.263
R&Di	42,846	0.006	0.019	-0.019	0.000	0.000	0.004	0.571
Japan								
g1lnTFP	22,981	0.008	0.040	-0.740	-0.012	0.008	0.028	0.515
Ndist	22,981	0.102	0.072	-0.379	0.057	0.102	0.146	0.686
Adist	22,981	0.154	0.094	-0.290	0.091	0.150	0.212	0.850
GNfrontier	22,981	0.011	0.027	-0.187	-0.002	0.010	0.023	0.160
Age	22,981	52.379	15.888	0	42	51	62	117
Foreign ownership	22,981	0.050	0.079	0.000	0.004	0.018	0.063	0.782
R&Di	22,981	0.018	0.028	0.000	0.000	0.007	0.025	0.831
Taiwan								
g1lnTFP	9,117	0.031	0.096	-0.688	-0.016	0.030	0.076	0.965
Ndist	9,117	0.157	0.128	-0.365	0.073	0.144	0.221	0.965
Adist	9,117	0.421	0.156	-0.230	0.319	0.408	0.505	1.215
GNfrontier	9,117	0.029	0.047	-0.312	0.013	0.042	0.056	0.338
Age	9,117	5.451	4.366	0.000	2.000	5.000	8.000	19.000

Table A3. Distribution of Sample

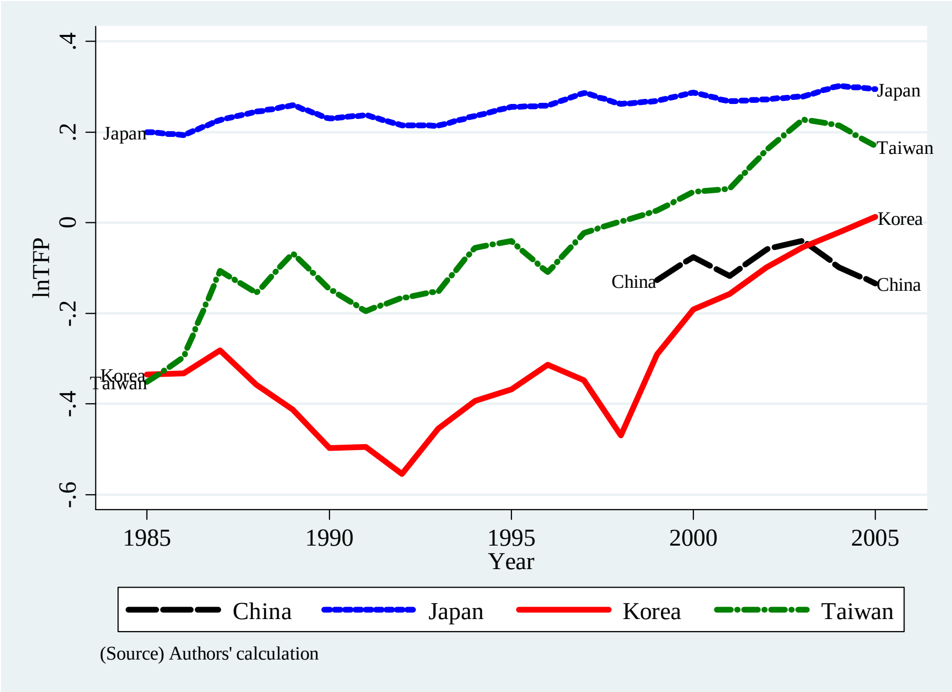
Industry	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total
1 Agriculture	13	14	17	19	19	21	22	23	23	19	22	27	24	27	46	56	50	53	55	60	57	667
2 Coal mining	6	6	6	6	6	6	7	7	7	7	8	8	8	9	14	15	17	18	19	22	22	224
3 Metal and non-metallic mining	4	5	5	5	5	5	6	7	7	9	9	15	18	25	24	25	28	27	28	30	29	316
4 Oil and gas extraction	3	3	3	3	3	3	3	3	3	3	3	3	3	3	6	6	7	9	9	9	8	96
5 Construction	259	285	307	311	353	392	477	514	530	557	620	759	846	925	919	945	990	1073	1188	1260	1210	14720
6 Food and kindred products	197	206	226	239	253	263	289	300	312	311	314	346	349	377	409	417	410	440	449	479	462	7048
7 Textile mill products	79	89	99	111	125	131	154	157	157	148	155	166	180	192	197	206	214	232	243	237	226	3498
8 Apparel	60	70	74	79	92	93	110	118	125	130	140	150	153	161	155	144	149	157	172	175	167	2674
9 Lumber and wood products	10	10	11	12	12	13	16	17	17	19	19	22	25	32	41	39	37	38	38	44	45	517
10 Furniture and fixtures	14	15	16	17	19	21	22	24	24	25	27	32	40	39	42	49	51	56	58	61	61	713
11 Paper and allied products	71	81	86	89	92	99	109	114	110	118	127	130	128	132	138	150	152	166	181	176	158	2607
12 Printing, publishing, and allied products	35	35	44	52	59	71	88	93	92	102	111	137	143	169	167	154	200	257	265	269	254	2797
13 Chemicals	313	332	358	392	428	441	487	511	510	520	555	589	603	647	752	774	836	913	925	958	914	12758
14 Petroleum and coal products	20	20	23	21	22	23	25	25	23	24	24	27	28	31	51	47	47	53	54	52	48	688
15 Leather	11	11	16	18	22	23	27	27	27	26	26	28	27	30	30	29	25	25	33	38	32	531
16 Stone, clay, and glass products	129	144	155	169	175	183	203	212	210	213	220	249	252	275	287	296	313	336	361	374	355	5111
17 Primary metal	166	174	183	200	227	244	277	285	288	303	328	356	392	420	470	471	505	587	580	601	572	7629
18 Fabricated metal	98	106	117	144	163	164	181	196	186	201	221	269	295	332	355	380	417	462	472	483	469	5711
19 Non-electrical machinery	221	230	269	292	317	338	373	387	376	397	439	592	665	762	829	860	952	1043	1084	1143	1071	12640
20 Electrical and electronic machinery	265	296	352	384	437	469	554	591	616	676	759	925	1088	1284	1566	1709	1946	2181	2293	2380	2311	23082
21 Motor vehicles	135	160	187	205	230	241	281	287	292	322	357	383	438	469	583	610	647	736	760	771	737	8831
22 Transportation equipment and ordnance	36	34	39	43	44	44	46	51	53	53	59	77	99	108	128	137	139	159	162	167	164	1842
23 Instruments	48	50	59	65	67	72	81	82	83	90	99	132	144	167	195	193	217	242	256	266	253	2861
24 Rubber and miscellaneous plastics	62	79	96	114	123	128	152	161	161	171	188	218	256	296	312	325	348	399	428	446	405	4868
25 Miscellaneous manufacturing	25	26	38	42	47	49	52	58	60	61	64	77	86	98	109	115	115	122	122	126	119	1611
26 Transportation	153	168	180	193	215	213	234	241	247	259	263	273	282	289	308	324	328	338	342	363	360	5573
27 Communications	3	5	7	6	9	9	9	11	14	14	16	17	16	26	64	66	66	76	84	88	89	695
28 Electricity utilities	9	10	10	12	12	12	12	13	13	13	13	14	14	14	47	50	57	68	65	72	75	605
29 Gas utilities	23	25	27	26	26	28	32	35	37	36	37	39	41	40	29	33	33	34	36	35	34	686
30 Trade	289	301	346	391	433	474	505	537	585	647	689	732	759	794	885	910	931	959	986	998	1015	14166
31 Finance, insurance, and real estate	72	78	95	115	124	127	153	163	153	144	140	152	166	173	188	203	219	237	280	309	317	3608
32 Other private services	171	199	234	276	317	344	384	411	436	480	541	597	643	715	797	868	968	1041	1100	1187	1232	12941
33 Public services		1	2	3	4	2	6	7	10	14	12	19	22	30	34	42	42	52	54	55	54	465
Total	3000	3268	3687	4054	4480	4746	5377	5668	5787	6112	6605	7560	8233	9091	10177	10648	11456	12589	13182	13734	13325	162779

Figure 1. TFP in Japan, Korea, Taiwan, and China: Chemical Industry



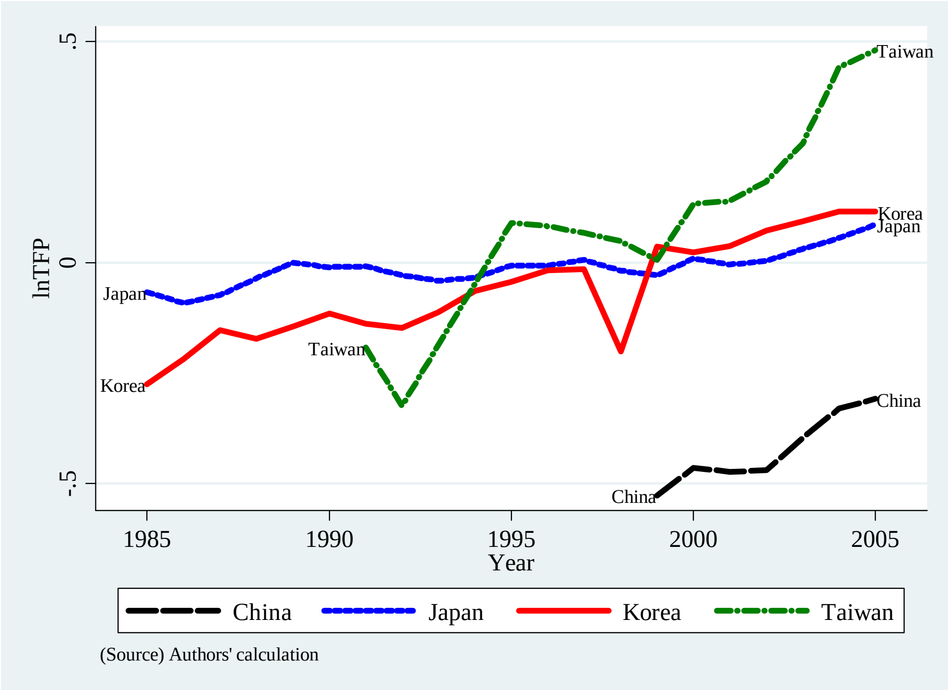
Source: Authors' calculations.

Figure 2. TFP in Japan, Korea, Taiwan, and China: Primary Metal Industry



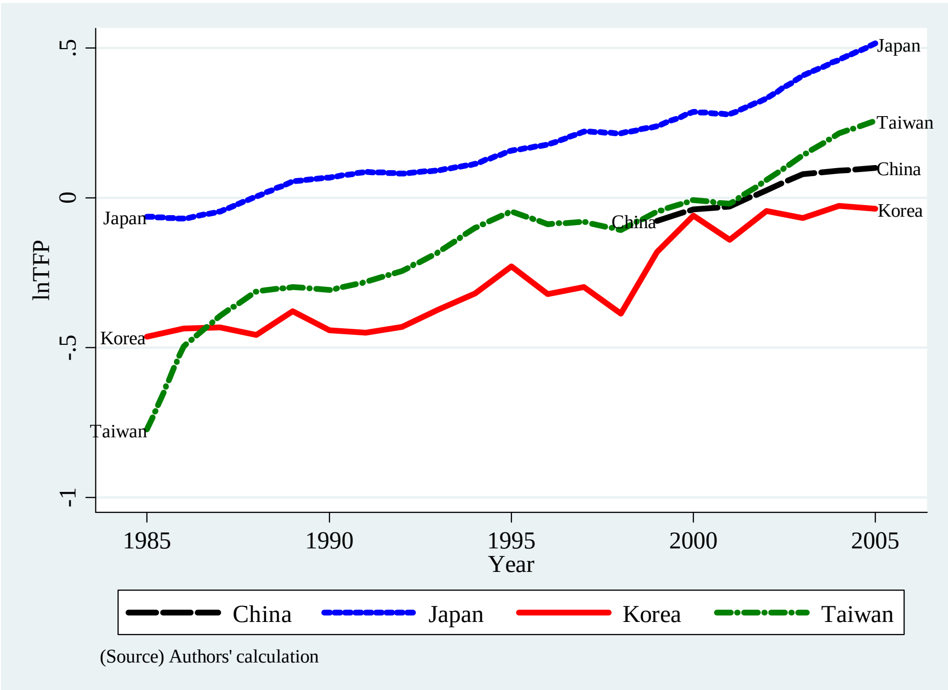
Source: Authors' calculations.

Figure 3. TFP in Japan, Korea, Taiwan, and China: Non-electrical Machinery Industry



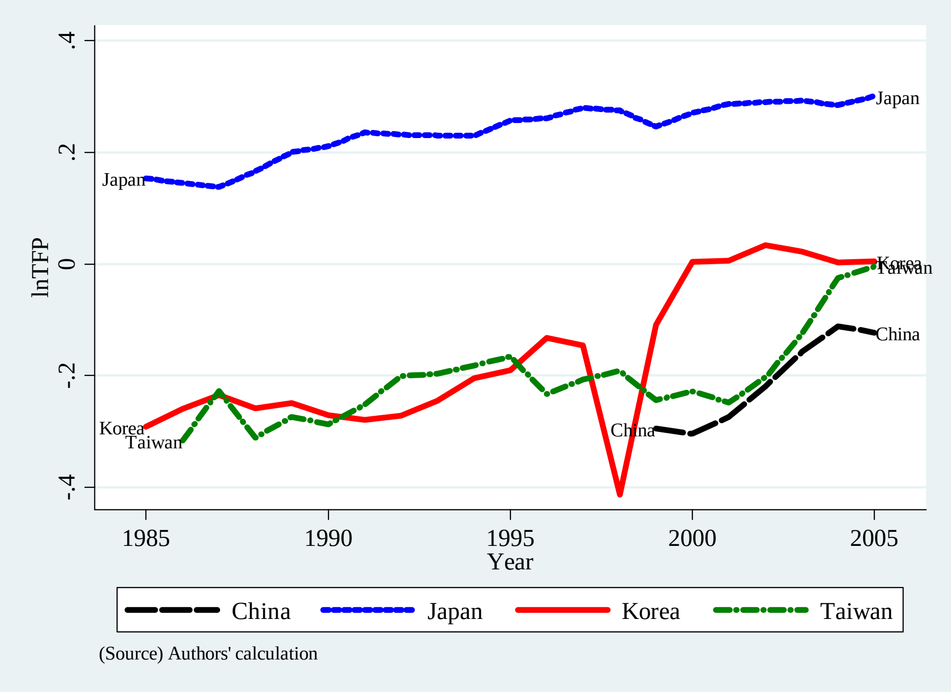
Source: Authors' calculations.

Figure 4. TFP in Japan, Korea, Taiwan, and China: Electrical Machinery Industry



Source: Authors' calculations.

Figure 5. TFP in Japan, Korea, Taiwan, and China: Motor Vehicle Industry



Source: Authors' calculations.