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Abstract

In this paper, we analyzed productivity catching up at the firm level in the Japanese, Korean, Taiwanese and Chinese manufacturing sector using the distance from the global technological frontier as a direct measure of the potential for technological frontier. We also examined the role of the absorption capacity for the technological catch-up by including the variables, such as R&D expenditure and foreign ownership in our empirical estimation model.

Our main results can be summarized as follows. First, although Japanese firms enjoy the highest average TFP level in many industries, their TFP growth rate has been relatively low during the past two decades. Taiwanese and Korean firms have achieved considerably high TFP growth in certain industries, and the some firms in the industries almost caught up or exceeded the Japanese firms' TFP level. 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 in other countries. In addition, Korean firms try to catch up the global frontier once they reached to the national frontier level TFP. Chinese firms are very slow in catching up and the only engine of the knowledge creation is firms located in the trade-oriented coast. Third, in the all four countries, the speed of the convergence of the firms far from the national frontier is faster than the firms near the frontier.

1. Introduction

In Japan, Korea, Taiwan, China and other East Asian countries, the expansion of foreign direct investment and the growth of China's economy have created a rapid increase of international trade and the division of labor. Korean firms such as Samsung Electronics and Hyundai Motor are now rapidly catching up with Japanese manufacturing firms. Meanwhile, through the conclusion of negotiations on a US-Korea Free Trade Agreement (FTA), the potential conclusion of the ongoing negotiations on a Japan-Korea FTA, and China's fulfillment of her World Trade Organization commitments, liberalization of the Chinese and Korean markets will continue. Against this background, the question of which industries and what type of firms will be able to thrive following such liberalization is becoming a hot topic in these two countries. Although how far Korean and Chinese firms have caught up with Japanese firms is an important question, very little research has been done on this topic.

The recent empirical and theoretical literature emphasized that the improvement in the productivity in the foreign countries can have positive impact on the domestic productivity and the catch up. Cameron, Proudman and Redding (2005) evaluate the role of technological transfer in explaining productivity growth at the industry-level in the United Kingdom since 1970. They found that R&D affects rates of UK productivity growth through innovation, while international trade facilitates the transfer of technology. Griffith, Redding and Van Reenen (2003, 2004) have examined both theoretically and empirically the role of R&D on the stimulating innovation, and the absorption capacity and convergence. They find evidence of R&D effects on both rates of innovation and technology transfer by using a panel of industries across twelve OECD countries. Kneller and Stevens (2006) investigate whether absorptive capacity helps to explain cross country differences in the technical efficiency. They empirically found that absorption capacity provides the useful explanation of the difference in industrial productivity between OECD countries. They claimed that human capital affects the production both directly and through its indirect effect through efficiency.

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, human capital, 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

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

contribution of resource reallocation across firms to aggregate productivity growth, based on the idea that aggregate productivity grows faster if more inputs and output are allocated to high-productivity firms and less to low-productivity firms.

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 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 frontier that is the hypothesized source of 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, they do manage to compile comprehensive firm-level data covering almost all firms in manufacturing and other industries. 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, we analyzed productivity catching up at the firm level in the Japanese, Korean, Taiwanese and Chinese manufacturing sector using the distance from the global technological frontier as a direct measure of the potential for technological frontier. Although most of the previous studies regard the US as the global productivity leader, we do not have a micro-data suitable for the measurement of the TFP in US firms. Hence we assumed the average of the TFP of firms within the top-duodecimal of the TFP distribution within four countries by industry and year as a global frontier. We also examined the role of the absorption capacity for the technological catch-up by including the variables, such as R&D expenditure and foreign ownership in our empirical estimation model.

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

[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). A comparative study of East Asian countries has been conducted by the ICPA (International Comparison of Productivity Among Asian Countries) project at RIETI (Research Institute of Economy, Trade and Industry) in Japan (see http://www.rieti.go.jp/jp/database/data/icpa-description.pdf).

growth in certain industries, and the some firms in the industries almost caught up or exceeded the Japanese firms' TFP level. 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 in other countries. In addition, Korean firms try to catch up the global frontier once they reached to the national frontier level TFP. Chinese firms are very slow in catching up and the only engine of the knowledge creation is firms located in the trade-oriented coast. Third, in the all four countries, the speed of the convergence of the firms far from the national frontier is faster than the firms near the frontier.

The remainder of this paper is organized as follows. Section 2 explains the estimation method used for the international comparison of firm-level TFP in Japan, Korea, Taiwan and China. Section 3 discusses the data we use in our empirical analysis in the next section and in Section 5 econometric results are presented and a final section 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 in Japan, Korea, and China

As a first step, we estimated each firm’s TFP level relative to the industry average TFP level in its country. We used the Multilateral TFP Index method developed by Good, Nadiri and Sickles (1997).[3] The adoption of 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=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, and

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

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

for $t>t_0$, and

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

for $t<t_0$, where $\ln Q_{f,t,j,m}$ stands for the real output (real sales) of firm *f* in year *t*, and $\ln X_{f,i,t,j,m}$ represents the natural logarithm of 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* for the sigma notation is 3 in this case. $S_{f,i,t,j,m}$ is the cost share 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.

The first line of equation (2) calculates the deviation of the TFP level of firm *f* from the average firm-level TFP in a given year, while the second line calculates the sum of the annual changes of the industry average of TFP from the benchmark year. The set of these two calculations makes it possible to conduct both a time-series and a cross-section comparison of firms' TFP levels.

Nominal output[4] and intermediate input were obtained from the financial statements of each firm. The real values of output and input were obtained by deflating nominal output and intermediate input using the price index for each industry[5] in each country. In order to take account of different depreciation rates for different assets, we estimated three types of capital assets – structures, machinery, and vehicles – separately, using the perpetual inventory method in Japan and Korea. In the case of Taiwan and China, we do not have such a detailed

[4] 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.

[5] 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 of firms in the stock market where the firm is listed.

information on the assets, we use total investment series for the estimation of 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.

Firm *f*'s cost of capital for each type of asset is obtained by multiplying the capital stock by the capital service price.[6] The capital service prices are calculated by the following equation:

$$c_{f,l,t,j,m} = \frac{1 - z_{f,l,t,i,m}}{1 - u_{t,m}} p_{l,t,m} \{\lambda_{f,t,j,m} R_{B,t,m} - (1 - u_{t,m})(1 - \lambda_{f,t,j,m}) R_{L,t,m} + \delta_{l,m} - (\ln(p_{l,t+1,m}) - \ln(p_{l,t,m}))\} \quad (4)$$

where $p_{l,t,m}$ stands for the price of investment good l in year t in country m, $u_{t,m}$ is the effective corporate tax rate, $R_{B,t,m}$ is the long-term government bond rate, $R_{L,t\,m}$ is the long-term lending rate, $\lambda_{f,t,j,m}$ is the own-capital ratio of firm f, and $\delta_{l,m}$ is the depreciation rate of asset l in country m. Meanwhile, $z_{f,l,t,j,m}$ is the expected present value of tax saving due to depreciation allowances on one unit of investment, which was obtained using the following equation:

$$z_{f,l,t,j,m} = \frac{u_{t,m}\delta_{l,m}}{\lambda_{f,t,j,m} R_{B,t,m} - (1 - u_{t,m})(1 - \lambda_{f,t,j,m}) R_{L,t,m} + \delta_{l,m}} \quad (5)$$

We obtain the cost for materials and labor from the financial statements of each firm.

The cost shares of the three production factors differ substantially in the three countries. Tables 1 to 3 show changes in the cost share of each production factor for the manufacturing and non-manufacturing sectors in Japan, Korea, Taiwan and China. While in Japan, the cost share of each production factor remained relatively stable, in Korea, the cost share of capital declined from 14 % in 1995 to 5% in 2005 in the manufacturing sector. The declines are mirrored by a rise from 75 % to 83 % in the cost share of intermediate input in the sector, which probably largely reflects the increasing division of labor between firms in the period. Both Taiwanese and Chinese firms are characterized by a high intermediate cost shear and a low labor cost share compared to their Japanese and Korean counterparts. In the manufacturing sector, the intermediate cost share 87% and 81% in Taiwan and China in 2005, respectively. The labor cost share was 8 and 9 % in China and Taiwan respectively in 2005, considerably lower than the 16% for Japan and 12% for Korea. Taiwanese manufacturing sector increased the intermediate cost share similar to that in Korea since 1990.

[6] The method of estimating the capital service price in principle is based on equation (4). However, it should be noted that the estimation methods for Japan, Korea, Taiwan and China slightly differ because of data constraints.

Table 1. Cost Share of Labor （%）

		1985	1990	1995	2000	2005
Japan	Manufacturing	17	16	18	17	16
	Non-manufacturing	28	28	30	30	30
Korea	Manufacturing	11	12	11	11	12
	Non-manufacturing	16	14	13	13	14
Taiwan	Manufacturing	6	11	12	10	9
	Non-manufacturing	13	14	12	9	9
China	Manufacturing				8	8
	Non-manufacturing				11	11

Source: Authors' calculations.

Table 2. Cost Share of Capital （%）

		1985	1990	1995	2000	2005
Japan	Manufacturing	4	5	5	5	4
	Non-manufacturing	6	6	6	5	4
Korea	Manufacturing	8	13	14	8	5
	Non-manufacturing	6	19	16	7	8
Taiwan	Manufacturing	16	11	8	7	4
	Non-manufacturing	14	13	11	8	8
China	Manufacturing				13	11
	Non-manufacturing				19	18

Source: Authors' calculation.

Table 3. Cost Share of Intermediate Input (%)

		1985	1990	1995	2000	2005
Japan	Manufacturing	79	79	77	78	80
	Non-manufacturing	66	66	64	65	67
Korea	Manufacturing	81	74	75	81	83
	Non-manufacturing	78	67	71	80	78
Taiwan	Manufacturing	78	77	80	82	87
	Non-manufacturing	73	73	77	83	83
China	Manufacturing				79	81
	Non-manufacturing				70	71

Source: Authors' calculation.

2.2. Purchasing Power Parities (PPPs) for Industry Output

In order to compare TFP levels of firms across countries, we need to take account of the difference of 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 three countries into a common currency unit. In this study, as mentioned earlier, we obtained PPP data for industry output from the results of the ICPA project. When comparing per-capita GDP across countries, usually PPPs based on price information of the final expenditure side are used, such as the PPPs of the International Comparison Program (ICP). But in order to compare TFP levels across countries, we need PPPs for domestic output and intermediate input, which are difficult to estimate from price information of the final expenditure side. Following the methodology of the ICOP project of Groningen University, the ICPA project mainly used information of 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*, $uv_{s,i,m}$ is computed by dividing the output of product $o_{s,j,m}$ by its quantity $q_{s,j,\,m}$, as shown below:

$$uv_{s,j,m} = \frac{o_{s,j,m}}{q_{s,j,m}} \tag{6}$$

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

$$UVR_{s,j,B,A} = \frac{uv_{s,j,A}}{uv_{s,j,B}} \tag{7}$$

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

$$UVR_{j,B,A} = \sum_{s=1}^{S_j} \omega_{s,j} UVR_{s,j,B,A} \tag{8}$$

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*.[7]

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

2.3. Methods for International Comparison of Firms' TFP Level

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

$$\ln TFP_{f,t,j,m} = \left(\ln Q_{f,t,j,m} - \overline{\ln Q_{t,j}}\right) - \sum_{i=1}^{n} \frac{1}{2}\left(S_{f,i,t,j,m} + \overline{S_{i,t,j}}\right)\left(\ln X_{f,i,t,j,m} - \overline{\ln X_{i,t,j}}\right)$$
$$+ \sum_{s=1}^{t}\left(\overline{\ln Q_{s,j}} - \overline{\ln Q_{s-1,j}}\right) - \sum_{s=1}^{t}\sum_{i=1}^{n}\frac{1}{2}\left(\overline{S_{i,s,j}} + \overline{S_{i,s-1,j}}\right)\left(\overline{\ln X_{i,s,j}} - \overline{\ln X_{i,s-1,j}}\right) \quad (2')$$

We employed this approach and measured the international comparable TFP in firms among the three countries. For this measurement, we adopted the Japanese Yen to express monetary values and converted values in Korean Won and values in Chinese Yuan into Yen using the PPPs for year 2000. In this analysis we chose year 2000 as our benchmark year, and the PPPs for year 2000 are estimated by taking into account of the differences of industrial price deflators between the countries and the PPPs estimation for year 1997 of the ICPA project, which are reported in Motohashi (2007). For output, we used production PPPs by industry to convert firms' output into Yen. For intermediate inputs, by utilizing the information about distribution margins and difference between the prices for domestic inputs and imported inputs in each country from Asian International Input-Output table 1995 prepared by Institute of Developing Economies- Japan External Organization, we estimated purchaser prices instead of producer prices and used this estimation as purchase price PPP.

For capital input PPPs, assets were divided into structures, machinery and vehicles. For structures, we used the production PPP for construction; for machinery, we used the simple average of the production PPP for the general machinery, electric machinery, and precision machinery industries; and for vehicles, we used the simple average of the output PPP for the motor vehicle and other transportation equipment industry.[8] As for labor input, work hours are directly compared and differences of labor quality resulting from differences in educational backgrounds are not controlled for. At this point, we do not have sufficient information for

[8] Since we have no information about the capital asset composition of capital stock in Taiwanese and Chinese firms, we applied the industrial share of each capital asset in Japan to the firms in the associated industry in each country. This information about capital asset composition was obtained form from Japan Industry Productivity Database2008.

estimating labor quality at the firm level in each country.[9]

Table 4. Relative Output, Capital and Intermediate Input Price (Japan=1)

		Relative Output Price			Relative Capital Price			Relative Intermediate Price		
		China	Korea	Taiwan	China	Korea	Taiwan	China	Korea	Taiwan
1	Agriculture	0.09981	0.49082	0.33419	0.23006	0.41827	0.30046	0.21659	0.48771	0.39488
2	Coal mining	0.08674	0.36588	0.97308	0.30597	0.47703	0.38189	0.27975	0.06866	0.47074
3	Metal and nonmetallic mining	0.20450	0.92902	0.83379	0.30724	0.47703	0.38189	0.28203	0.48875	0.44776
4	Oil and gas extraction	0.54682	0.40534	0.92432	0.30860	0.47703	0.38189	0.29207	0.27871	0.51645
5	Construction	0.23363	0.37675	0.26305	0.34583	0.49642	0.43152	0.31100	0.46226	0.49730
6	Food and kindred products	0.15904	0.50057	0.36739	0.35085	0.46906	0.38203	0.18484	0.60687	0.43306
7	Textile mill products	0.39278	0.63763	0.53775	0.31734	0.42877	0.35528	0.39931	0.56574	0.51005
8	Apparel	0.31203	0.79488	0.55977	0.33684	0.42877	0.35615	0.37699	0.51688	0.48647
9	Lumber and wood	0.26858	0.38444	0.33261	0.32952	0.47219	0.38829	0.25269	0.34705	0.38249
10	Furniture and fixtures	0.46609	0.41637	0.54229	0.33370	0.40566	0.38421	0.31354	0.48729	0.47622
11	Paper and allied	0.34669	0.76330	0.60562	0.33757	0.37659	0.36826	0.34313	0.64434	0.59644
12	Printing publishing and allied	0.33309	0.61988	0.43394	0.38668	0.39073	0.40426	0.32727	0.55627	0.51651
13	Chemicals	0.44223	0.59418	0.48607	0.32183	0.45541	0.36567	0.34296	0.55163	0.53876
14	Petroleum and coal products	0.30923	0.41876	0.32194	0.31102	0.44563	0.35561	0.65655	0.69354	0.75084
15	Leather	0.11292	0.43915	0.32400	0.35994	0.44078	0.38581	0.31551	0.49635	0.47950
16	Stone clay glass	0.45237	0.53245	0.56898	0.30375	0.45567	0.37008	0.28751	0.46641	0.56231
17	Primary metal	0.50520	0.81384	0.65314	0.29080	0.46182	0.35044	0.42843	0.64851	0.58719
18	Fabricated metal	0.35681	0.48533	0.53413	0.29390	0.44401	0.34589	0.38462	0.58781	0.53831
19	Machinery non-elect	0.46911	0.46771	0.41184	0.34607	0.45895	0.39961	0.39010	0.52691	0.53151
20	Electrical machinery	0.45548	0.64864	0.68480	0.34259	0.47358	0.40227	0.41284	0.44904	0.58745
21	Motor Vehicles	0.66475	0.79192	1.02436	0.34581	0.40145	0.36318	0.50711	0.69528	0.73716
22	Transportation equipment and ordnance	0.51488	0.53374	0.78197	0.33667	0.41681	0.38368	0.43683	0.53423	0.66417
23	Instruments	0.47891	0.82949	0.71732	0.36211	0.46758	0.41429	0.37750	0.57174	0.55183
24	Rubber and misc plastics	0.24838	0.63629	0.75073	0.34810	0.41379	0.37347	0.36427	0.54842	0.55224
25	Misc manufacturing	0.37823	0.59124	0.55437	0.35718	0.42940	0.40016	0.30686	0.47288	0.46353
26	Transportation	0.23682	0.43090	0.80774	0.28015	0.44474	0.35308	0.32397	0.50900	0.50784
27	Communication	0.47577	0.66715	0.32542	0.29718	0.48468	0.38030	0.22157	0.49584	0.36799
28	Electrical utilities	0.27678	0.50212	0.49637	0.26242	0.45249	0.33874	0.29613	0.53737	0.59002
29	Gas utilities	0.18940	1.21548	2.16558	0.23437	0.39812	0.28205	0.30284	0.52673	0.62251
30	Trade	0.07573	0.57793	0.44358	0.28188	0.40398	0.34778	0.25113	0.35496	0.37844
31	Finance Insurance and Real Estate	0.30548	0.46233	0.24143	0.24655	0.37071	0.28599	0.25170	0.42165	0.30939
32	Other private services	0.03232	0.21379	0.25151	0.31111	0.42226	0.39094	0.25733	0.36155	0.37025
33	Public service	0.12948	0.36384	0.91466	0.29486	0.42516	0.35994	0.28375	0.49661	0.45678

Source: Authors' calculation.

2.4. Results for International Comparison of Firms' TFP Level

2.4.1 Comparison of TFP Growth in Japan, Korea Taiwan and China: Manufacturing and Non-manufacturing[10]

The growth rate of TFP in Japan's manufacturing sector slowed down markedly in the first half of the 1990s before accelerating again in the second half of that decade and again in the early 2000s. In Korea, the manufacturing sector TFP growth rate was negative in the latter half of the 1980s, but was turned into positive territory in the early 1990s, and was accelerated in the latter half of 1990s. Yet, Korea's rate of TFP growth in 2000-05 has become lower compared with the 1990s. Taiwanese Manufacturing sector enjoyed very high TFP growth rates in the period between 1985 and 2005, except the latter of the 1990s due to the financial crisis. The growth rate of TFP in Chinese Manufacturing sector in 2000-2005 was very slow and

9 For more detailed explanation of the measurement method of TFP, see Inui, Kabe and Kim (2008).

10 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.

Chinese manufacturing sector was far behind in catching up in other thee rivals in East Asia.

In the non-manufacturing sector, TFP growth tended to be low relative to the manufacturing sector until 2000 in Japan. In 2000-2005, however, the rate of non-manufacturing TFP growth topped 2% in Japan to exceed that for the manufacturing sector. In the 1990s, Korean non-manufacturing sector had a high TFP growth and it was higher than those in the sector in Taiwan and Japan during the period. Taiwanese non-manufacturing sector have experienced a strong TFP growth rate in the 1985-2005 period, but slower than that in the Taiwanese manufacturing sector in the most of the periods. The TFP in China's non-manufacturing sector showed a large negative growth in the 2000-05 period, mainly because of the large decline in Oil and Gas Extraction Sector's TFP in China.

Table 5. 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				0.80%
	Non-manufacturing				-3.34%

Source: Authors' calculations.

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

Figures 1 through 5 show a comparison of the TFP levels of listed firms from Japan, Korea, Taiwan and China in five different industries: the chemical, the primary metal, the machinery, non electric and the electric machinery, and the motor vehicle manufacturing industry.

For the chemical industry (including pharmaceuticals, see Figure 1), average Taiwanese firms' TFP has increased very rapidly in the early 2000s and it has caught up the average Japanese firms in 2005. Korean firms' TFP growth was very slow between 1985 and 2000 and the TFP level is staying low relative to those of Japanese and Taiwanese counterparts. Chinese chemical firms are far outstripping the TFP levels of major Japanese and Taiwanese chemical firms.

In the primary metal sector (Figure 2), Taiwanese firms has increased their TFP levels steadily in the estimation period and almost caught up Japanese firms' TFP in 2003. Korean average TFP in the sector plummeted in the late 1980s and the early 1990s and it is lag far behind the ones in Japan and Taiwan. China have not improved much, staying low relative to those in other three countries.

In the machinery industry (Figure 3), due to high TFP growth rates in Taiwanese firms, the levels have been higher than those of Japanese and Korean firms in the early 2000s. The levels of TFP are almost same among Japanese and Korean firms since 1995. The TFP levels of Chinese machinery makers remain very low relative to those of their Japanese, Korean and Taiwanese rivals.

In the electrical machinery industry (Figure 4), all of the four countries have experienced steady improvements of TFP levels in 1985-2005 period. The tempo of the improvements of TFPs in Chinese and Taiwanese firms has been faster than that in Korean firms, the average TFP level of Korean firms become lower than those in Japan, Taiwan and even China in 2005.

In the Motor vehicle industry (Figure 5), the TFP levels of Japan are considerably higher than those of their Korean, Taiwanese and Chinese counterparts, although the three countries have experienced the large improvement of the TFP levels in the early 2000s.

2.5. International Comparison of Firms' ROA Level in Japan, Korea, and China

In this section, we compare ROA (return on assets) of firms in Japan, Korea and China in order to compare the corporate profitability and asset efficiencies in these three countries. ROA is determined by the three factors: (1)Capital-Labor ratio (K/L), (2) TFP, and (3) Capital Revenue Ratio.

Among three countries, Japan firms' ROA is lower than that in Korea and China both in the manufacturing sector and non-manufacturing sector. Japanese firms' TFP level is higher than the two countries, low ROA in Japanese firms mainly dues to the high capital labor ratios and low capital revenue ratios in Japanese firms. In Korea, ROA is declining very rapidly from 10.7% in 1985 to 4.9% in 2005 in the manufacturing sector, and from 7.4% in 1985 to 1.9% in 2005 in the non-manufacturing sector. Korean non-manufacturing sector's ROA in 2005 is even lower than that in the Japanese non-manufacturing sector. This decline in ROA brought by the rapid increase in capital labor ratio and sluggish TFP improvement in the 2000-05 period. Chinese firms enjoyed very high ROA, even they suffered from low TFP level.

Table 6. Firms' ROA Level in Japan, Korea, and China

		1985	1990	1995	2000	2005
Japan	Manufacturing	5.30%	5.80%	3.50%	3.90%	4.40%
	Non-manufacturing	4.90%	5.90%	4.30%	4.40%	5.60%
Korea	Manufacturing	10.70%	8.70%	7.80%	7.60%	4.90%
	Non-manufacturing	7.40%	6.30%	5.80%	6.20%	1.90%
China	Manufacturing				11.50%	12.50%
	Non-manufacturing				8.90%	10.40%

Source: Authors' calculations.

3. Data for the Estimation

As described in the TFP estimation method in the above, the level of TFP of firms is in logarithmic value. The dependent variable, one-year growth rate of TFP of a firm, is defined as the difference in the firm TFP levels between this period and the next. We defined and measured two kinds of productivity frontier, that is, East-Asian frontier, and National frontier. First we divided all the firms into four groups according to their TFP level of the year by country and industry, and took the average of the TFP level of top group to define the values as national frontiers. As for the East-Asian frontier, we assumed it to be similar to the national frontier of Japan in all the industries in a earlier version of this paper. But since we found that in some industries, the national frontier of Korea, China and Taiwan is higher than that of Japan, we defined the East-Asian frontier in a different way in this version. First we divided all the firms of China, Korea, Taiwan and Japan into sixteen groups (intuitively four groups for each country) according to their productivity level, and defined the East-Asian frontier as the average TFP level of the top group firms.

The distance of each firm to the national frontier (East-Asian frontier) is measured as a difference between the firm's TFP level and the average TFP for that national (East-Asian) top group.

Other explanatory variables are defined and measured as follows. Firm age is measured as the year difference between the establishment year and the current year. As for the Chinese firms, since the information on establishment year is not available, the difference between the year of listing and the current year is used. We include in the Chinese estimations a dummy variable which takes the value of 1 when the firm is located in the coastal area and 0 otherwise. The ratio of the foreign ownership is measured as the ratio of the number of the stock owned by foreigners over the total number of the stock issued. R&D intensity is measured as the ratio of

R&D expenditure over sales. We assumed that the firms which do not report R&D expenditure are not R&D performers. Export ratio is defined and measured as the ratio of the total volume of exports over sales. We also assume that the firms not reporting exports are not exporters.[11] We also define a business group dummy variable that takes the value 1 when a firm is an affiliate of one of the top 30 business groups and 0 otherwise. These last two variables are used only in the estimation with Korean data.

Our estimation will also include as explanatory variables the products of these variables with the distance to the national frontier and the distance to the East-Asian frontier.

As a robustness check, we also measure R&D intensity and export ratio as their difference from the industry averages.

In our sample, since some firms report implausibly high or low TFP growth rates, we trimmed the upper 2.5% and the lower 2.5% observations for every country and every manufacturing industry.

4. Model and Estimation Procedure

In this section, following the methodology employed by Bartelsman, Haskel and Martin (2006), we estimate the speed of convergence to the productivity frontier. Like Bartelsman, Haskel and Martin (2006), we assume that changes in the knowledge capital of firm f, ΔA_f, originate from changes in the knowledge stock within the firm itself and from outside the firm, because knowledge inputs are potentially transferable and non-rival within and across firms. Therefore, we may write:

$$\Delta A_f = f\left(X_f, A_f, A_{\_f}\right) \qquad (4)$$

where X_f are the physical inputs into the idea process. Log linearizing this yields:

$$\Delta \ln A_f = \alpha_1 \ln X_f + \left(\alpha_2 - \alpha_3\right) \ln A_f + \alpha_3 \ln\left(\frac{A_{\_f}}{A_f}\right) \qquad (5)$$

where it is usual to impose $\alpha_2=\alpha_3$, so the overall growth of A only depends on the relative levels of $A_{\_f}$ and A_f. As in Bartelsman, Haskel, and Martin (2006) and other studies in the convergence literature, we identify $A_{\_f}$ as the productivity level of the leading firm in a nation or the four countries. We refer the average productivity level of the top-quartile firms as the national frontier, A_N. The term $\ln(A_N/A_f)$ indicates the productivity gap between the national frontier and

[11] Since report on R&D and export was not compulsory in Japan and Korea, those variables may include serious measurement error.

firm *f*. We refer to the average TFP of firms within the top-duodecimal of the TFP distribution across the three countries by industry and year as the global frontier, A_G.

Using firm-level TFP as a proxy for firms' knowledge capital, we can estimate the version of (5) given by:

$$\Delta \ln A_i = \alpha_1 \ln X_i + \alpha_{2N} \ln\left(\frac{A_N}{A_i}\right) + \alpha_{2G} \ln\left(\frac{A_G}{A_i}\right) \qquad (6)$$

where α_2 measures the pull from the frontier. If the marginal effect of technology spillovers or diffusion is larger for firms with a low TFP level,[12] the value of α_{2N} and α_{2G} will be positive and we will see a catching-up of low-productivity firms both to the national and global frontiers. We include a proxy for investment in knowledge creation such as R&D intensity (data is available for Korea and Japan), firm age, export ratio (data is available only for Korea) and a dummies for the firm within corporate group in Korea and for the firm located in the coastal region in China. In addition, we include the growth potential of the industry to control for industry characteristics. The growth potential is measured as the average growth rate of both global and national frontiers. We also consider the possibility that α_{2N} and α_{2G} vary linearly with the (log) distance and estimate the equation below.

$$\Delta \ln A_i = \alpha_1 \ln X_i + \alpha_{2N}^1 \ln\left(\frac{A_N}{A_i}\right) + \alpha_{2N}^2 \ln\left(\frac{A_N}{A_i}\right)^2 + \alpha_{2G}^1 \ln\left(\frac{A_G}{A_i}\right) + \alpha_{2G}^2 \ln\left(\frac{A_G}{A_i}\right)^2 \qquad (7)$$

A second approach is to let α_{2N} and α_{2G} be functions not of distance but of absorption capacity proxies at the firm level such as R&D, exports, age, MNE status and coastal location.

$$\alpha_{2N} = \theta_0 + \theta_1 \ln(\frac{RD_i}{Y_i}) + \theta_2 \ln(\frac{EX_i}{Y_i}) + \theta_3 Age_i + \theta_4 MNE\_dummy_i + \theta_5 Coast\_dummy_i \qquad (8)$$

$$\alpha_{2G} = \mu_0 + \mu_1 \ln(\frac{RD_i}{Y_i}) + \mu_2 (\frac{EX_i}{Y_i}) + \mu_3 Age_i + \mu_4 MNE\_dummy_i + \mu_5 Coast\_dummy_i \qquad (9)$$

5. Estimation Results

The estimation results of equation (6) are shown in Table 11. Here we only include the

[12] 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).

firm's age as a proxy for investment in knowledge creation. Column 1 shows the results for the complete sample of firms (in the three countries). The marginal pull from the national frontier is 0.277 and from the global frontier is 0.006, respectively. In order to examine whether the pull from the national frontier and global frontier is different among countries, we estimated the equation (6) for each country (China, Japan, Korea, and Taiwan) separately. The result is shown in column 2, 3, 4 and 5 and indicates that the marginal impact of the national frontier is largest for Korean firms, followed by that for Taiwan, China and then Japanese firms. This result suggests that the convergence speed to the national frontier is the weakest for Chinese firms. Looking at the convergence speed to the global frontier for Korean, Chinese and Taiwanese firms (columns 2, 4 and 5), we find that the marginal impact of the global frontier on Korean TFP growth is much smaller than that of the Korean national frontier (0.025 and 0.294 respectively), but it is statistically significant. However, in the case of Chinese and Taiwanese firms, the marginal impact of the global frontier is smaller than that of the Chinese and Taiwanese national frontiers and statistically insignificant. This results indicate only Korean firms are continuing to try to catch up to the global frontier once they reached to the national frontier.

Table 12 shows the estimation results of equation (7). We allow the marginal impact of distance to frontier (DTF) to vary by simply allowing the marginal impact to vary linearly with DTF, which implies entering a linear and squared term. As column 1 shows, the effect of National DTF is increasing with distance, with both positive in linear and squared terms.

We substitute equation (8) and (9) into equation (6) and estimate the obtained equation in order to capture the effect of absorption capacity on the catching up to the frontier. Here we include R&D intensity (data is available for Korea and Japan), firm age, export ratio (data is available only for Korea), dummy for the firms in the corporate group in Korea and dummy for coastal location in China as proxies for investment in knowledge creation and the absorption capacity. As in Table 13, coastal location plays a significant role for the creation but not the foreign-owned multinational status in China. The firm's age has a positive impact on the catching-up to the global frontier. Colum 2 in Table 13 shows the results for Korean firms. The participation in corporate group contributes to the increase in the absorption capacity when the firms are trying to catch up to the global frontier, but it is not the case for catching up to the national frontier. Export activity contributes negatively to the catching up to the global frontier in Korea. In addition, firm's age has a positive impact on the creation of the knowledge, but a negative impact on the catching up.

In order to take into account the possible multicollinearity problem between the explanatory variables, we estimated the catch-up model with absorption capacity while dropping the various explanatory variables one at a time (results are in Table 14). We obtained virtually unchanged results in Table 13. In case of Japan, R&D intensity has a positive impact on the knowledge creation and the foreign participation contributes positively to the catching up to the global frontier. As a robustness check, we define R&D intensity and export ratio as difference to the industry averages. The results are reported in Table 15 and Table 16 and again we get similar results to those in Table 13 and Table 14.

Figure 1 Comparison of Chemicals Industry TFP in Japan, Korea, Taiwan and China

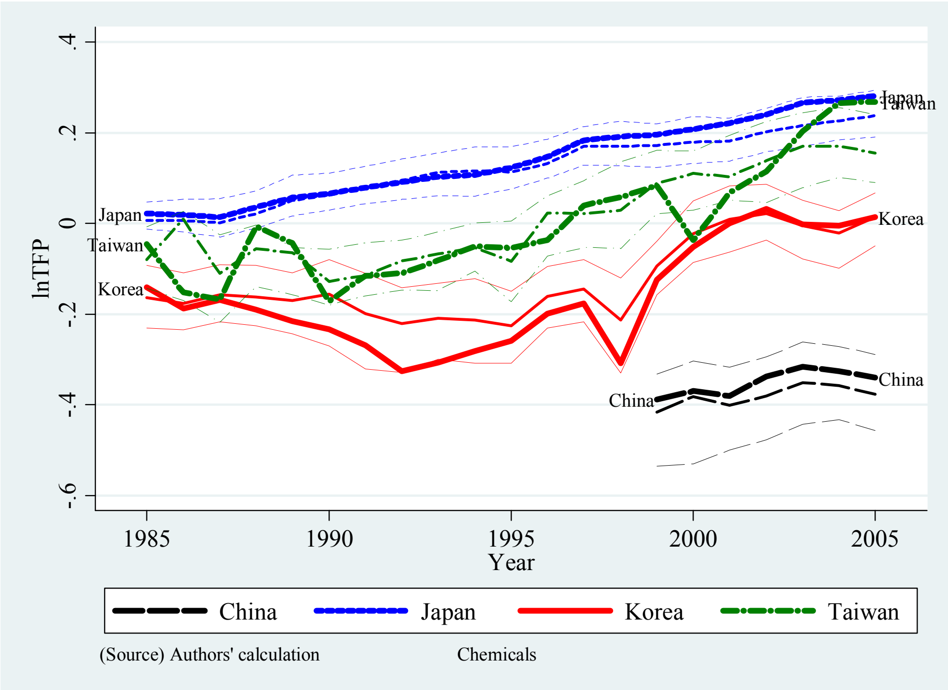

Figure 2 Comparison of Primary Metal Industry TFP in Japan, Korea, Taiwan and China

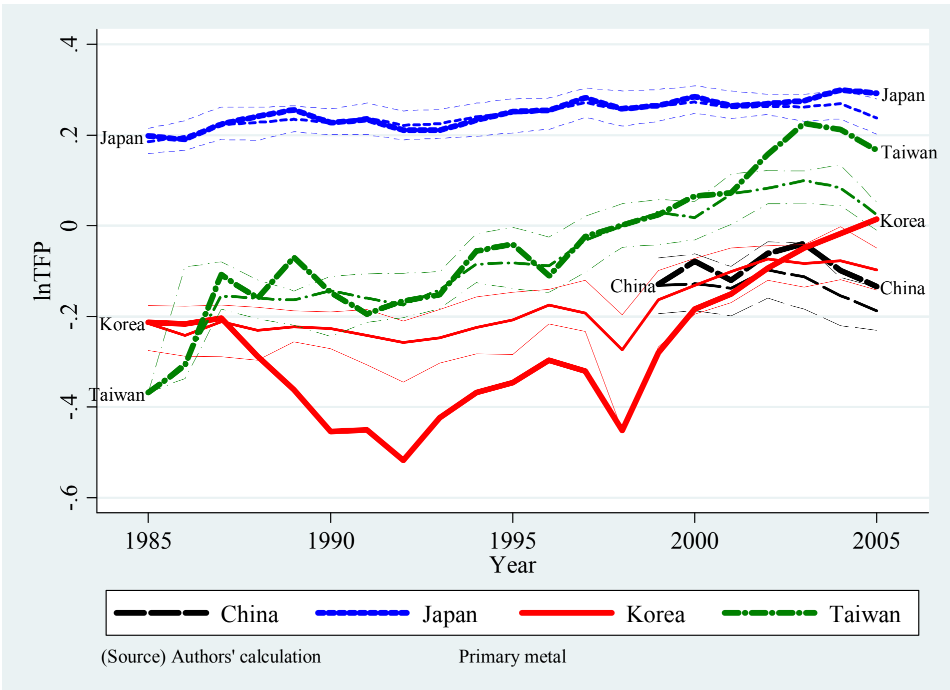

Figure 3 Comparison of Machinery, non-electrical Industry TFP in Japan, Korea, Taiwan and China

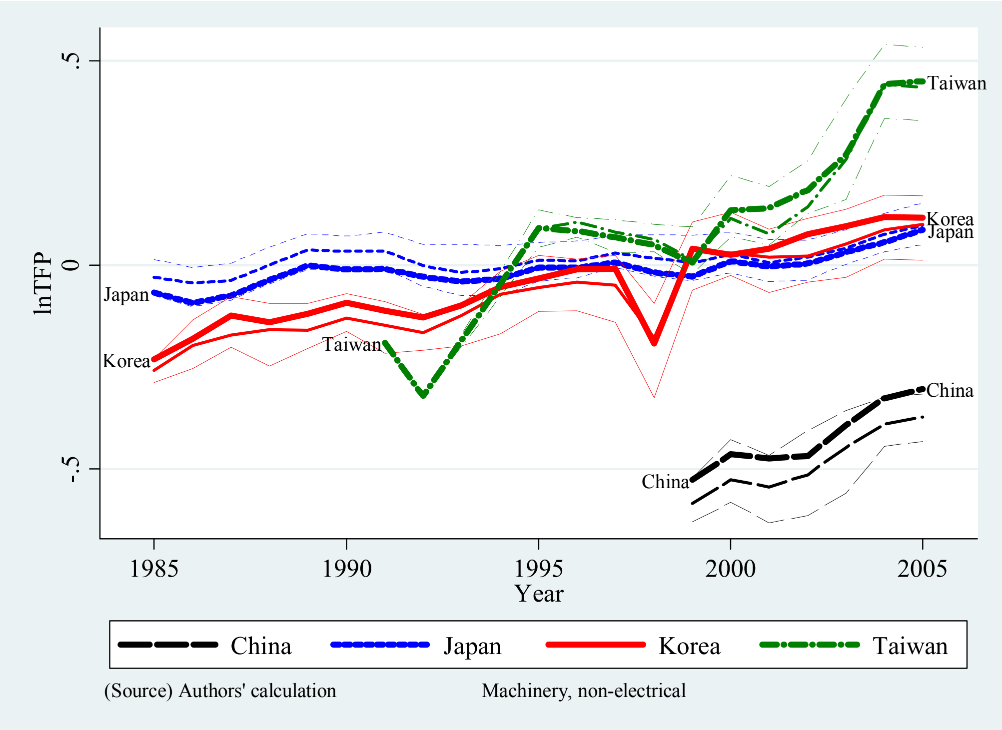

Figure 4 Comparison of Electrical Machinery Industry TFP in Japan, Korea, Taiwan and China

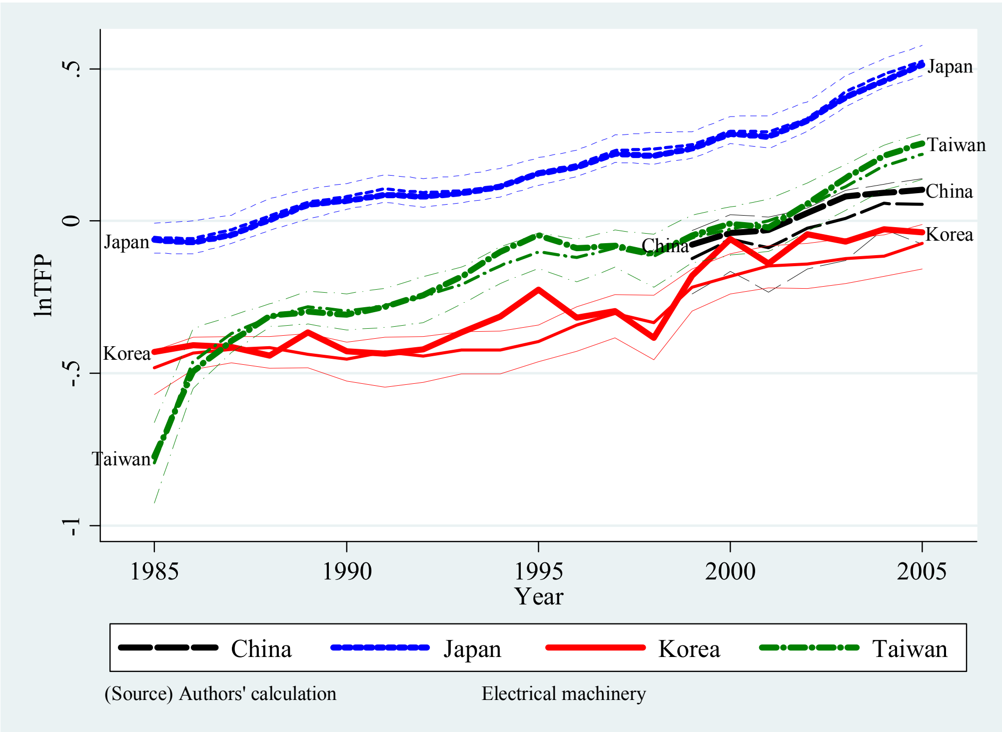

Figure 5 Comparison of Motor Vehicle Industry TFP in Japan, Korea, Taiwan and China

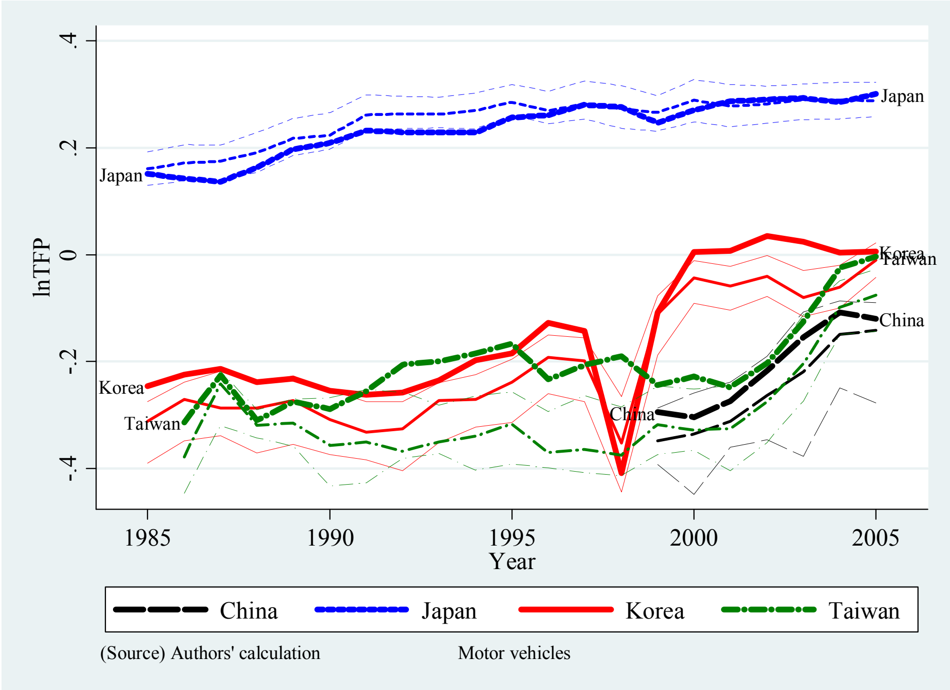

Table 7 Definitions

Variables	Definition
g1lnTFP	1 year growth rate of TFP from the current period to the next period
GAfrontier	1 year growth rate of East Asian frontier
GNfrontier	1 year growth rate of National frontier
Ndist	log distance of the TFP level from the National frontier
Gdist	log distance of the TFP level from the Global frontier
ratio_foreign	the ratio of the stock owned by foreigners
Dcoast	Dummy variable denoting whether the firm is located on a trade-oriented coast
exportratio	the ratio of export over the gross sales
dexportratio	=export ratio - industry average of export ratio
rndint	R&D intensity
drndint	= R&D intensity - industry average of R&D intensity
Dgroup	Dummy variable denoting whether the firm is a affiliate of the top-30 business group in Korea

Table 8 Summary Statistic 1

variable	N	mean	sd	min	p25	p50	p75	max
Whole sample								
g1lnTFP	91,148	0.016	0.115	-1.995	-0.025	0.012	0.052	1.286
Ndist	105,888	0.144	0.144	-0.924	0.067	0.127	0.196	1.585
Adist	105,846	0.386	0.251	-0.689	0.191	0.359	0.544	1.947
GAfrontier	97,250	0.013	0.033	-0.295	-0.005	0.010	0.031	0.339
GNfrontier	97,290	0.014	0.039	-0.312	-0.005	0.013	0.032	0.366
age	101,125	23.016	22.078	-16	6	14	37	125
China								
g1lnTFP	3,692	0.005	0.142	-0.959	-0.045	0.010	0.059	1.057
Ndist	4,565	0.195	0.188	-0.599	0.081	0.171	0.271	1.415
Adist	4,577	0.607	0.280	-0.281	0.417	0.611	0.796	1.804
GNfrontier	3,807	0.010	0.044	-0.218	-0.017	0.011	0.035	0.216
age	4,577	4.835	3.136	0	2	5	7	15
Dcoast	3,141	0.509	0.500	0	0	1	1	1
ratio_fore~n	3,098	0.012	0.053	0.000	0.000	0.000	0.000	0.558
Korea								
g1lnTFP	47,765	0.020	0.136	-1.163	-0.037	0.015	0.070	1.286
Ndist	58,492	0.157	0.154	-0.924	0.073	0.139	0.214	1.505
Adist	58,395	0.487	0.228	-0.689	0.332	0.468	0.622	1.947
GNfrontier	53,417	0.013	0.042	-0.295	-0.009	0.012	0.033	0.366
	58,492	14.031	11.320	-16.000	6.000	11.000	20.000	109.000
age	2,847	0.079	0.128	0.0001	0.0022	0.0192	0.1	0.9335
Dgroup	58,492	0.022	0.145	0	0	0	0	1
exportratio	58,492	0.168	4.607	0.000	0.000	0.000	0.092	734.263
rndint	57,806	0.008	0.025	-0.038	0.000	0.000	0.005	1.184
Japan								
g1lnTFP	29,924	0.007	0.056	-1.995	-0.013	0.007	0.029	1.106
Ndist	31,861	0.104	0.090	-0.590	0.056	0.104	0.152	1.585
Adist	31,831	0.155	0.107	-0.606	0.089	0.151	0.216	1.544
GNfrontier	30,228	0.011	0.026	-0.187	-0.003	0.010	0.023	0.160
age	27,013	52.614	17.553	0	41	51	62	125
ratio_fore~n	31,915	0.054	0.092	0.000	0.003	0.018	0.065	0.968
rndint	31,915	0.020	0.038	0.000	0.000	0.007	0.026	2.085
Taiwan								
g1lnTFP	9,767	0.033	0.125	-0.842	-0.019	0.030	0.079	1.081
Ndist	10,970	0.167	0.170	-0.751	0.073	0.146	0.229	1.492
Adist	11,043	0.426	0.189	-0.517	0.315	0.408	0.510	1.773
GNfrontier	9,838	0.030	0.046	-0.312	0.013	0.042	0.057	0.338
age	11,043	5.741	4.609	0.000	2.000	5.000	8.000	20.000

Table 9. Summary Statistic 2

After Data Cleaning								
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
ratio_fore~n	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
	42,846	13.938	10.125	0.000	6.000	12.000	20.000	73.000
age	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
exportratio	42,846	0.180	4.469	0.000	0.000	0.000	0.125	734.263
rndint	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
ratio_fore~n	22,981	0.050	0.079	0.000	0.004	0.018	0.063	0.782
rndint	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 10. 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 nonmetallic 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	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	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	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 glass	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 Machinery non-elect	221	230	269	292	317	338	373	387	376	397	439	592	665	762	829	860	952	1043	1084	1143	1071	12640
20 Electrical 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 misc plastics	62	79	96	114	123	128	152	161	161	171	188	218	256	296	312	325	348	399	428	446	405	4868
25 Misc 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 Communication	3	5	7	6	9	9	9	11	14	14	16	17	16	26	64	66	66	76	84	88	89	695
28 Electrical 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 service		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

Table 11. Estimation Result 1

	Global b/se	China b/se	Japan b/se	Korea b/se	Taiwan b/se
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	0.000 ***	0.001	0.000	0.000 ***	-0.001 ***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
D_China	-0.039 ***	0.000	0.000	0.000	0.000
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
D_Korea	-0.015 ***	0.000	0.000	0.000	0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
D_Taiwan	-0.019 ***	0.000	0.000	0.000	0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
R-squared	0.314	0.143	0.273	0.372	0.263
Observation	78,406	3,462	22,981	42,846	9,117

Table 12. Estimation Result 2

	Global b/se	China b/se	Japan b/se	Korea b/se	Taiwan b/se
Ndist	0.202 ***	0.098	0.076 ***	0.244 ***	0.126 ***
	(0.010)	(0.090)	(0.023)	(0.016)	(0.037)
Ndist2	0.171 ***	0.175 *	0.313 ***	0.127 ***	0.250 ***
	(0.029)	(0.102)	(0.095)	(0.035)	(0.080)
Adist	-0.03410 ***	-0.01510	-0.03490 **	0.00684	0.06740
	(0.007)	(0.093)	(0.014)	(0.017)	(0.052)
Adist2	0.04300 ***	0.02590	0.04420 *	0.01310	-0.02530
	(0.008)	(0.055)	(0.024)	(0.014)	(0.055)
GNfrontier	0.83300 ***	0.44500 ***	0.51500 ***	0.75700 ***	0.53500 ***
	(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)
age2	0.000 ***	0.000	0.000	0.000 ***	0.000 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
D_China	-0.042 ***	0.000	0.000	0.000	0.000
	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)
D_Korea	-0.012 ***	0.000	0.000	0.000	0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
D_Taiwan	-0.019 ***	0.000	0.000	0.000	0.000
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
R-squared	0.320	0.150	0.281	0.375	0.272
Observation	78,406	3,462	22,981	42,846	9,117

Table 13. Estimation Result 3

	China b/se		Korea b/se		Japan b/se	
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	0.48200	***	0.81000	***	0.49700	***
	(0.083)		(0.131)		(0.022)	
GAfrontier	-0.01140		-0.20200		-0.05620	***
	(0.138)		(0.153)		(0.011)	
age	0.001		0.002	**	0.000	
	(0.004)		(0.001)		(0.000)	
age2	0.000		0.000		0.000	
	(0.000)		(0.000)		(0.000)	
Dcoast	0.029	**				
	(0.012)					
Ratio_foreign	-0.051		0.003		0.015	
	(0.077)		(0.014)		(0.010)	
RNDi			0.201		-0.048	
			(0.547)		(0.054)	
exportratio			0.029			
			(0.025)			
Dgroup			0.008			
			(0.016)			
Ndist_age	-0.007		-0.004	*	0.000	
	(0.012)		(0.003)		(0.001)	
Ndist_coast	-0.030					
	(0.055)					
Ndist_foreign	0.097				-0.164	**
	(0.307)				(0.077)	
Ndist_rnd			0.343		0.725	
			(0.944)		(0.482)	
Ndist_export			0.114			
			(0.106)			
Ndist_group			-0.190	*		
			(0.115)			
Adist_age	0.009	*	0.000		0.000	
	(0.005)		(0.001)		(0.000)	
Adist_coast	-0.010					
	(0.021)					
Adist_foreign	0.065				0.038	
	(0.124)				(0.030)	
Adist_rnd			-0.663		0.170	
			(1.158)		(0.323)	
Adist_export			-0.101	*		
			(0.060)			
Adist_group			0.061	*		
			(0.037)			
R-squared	0.150		0.228		0.278	
Observation	2,816		1,601		22,981	

Table 14. Estimation Result 4

	China1	China2	Korea1	Korea2	Japan1	Japan2
	b/se	b/se	b/se	b/se	b/se	b/se
Ndist	0.266 ***	0.258 ***	0.335 **	0.293 *	0.138 ***	0.160 ***
	(0.092)	(0.092)	(0.147)	(0.150)	(0.033)	(0.037)
Adist	-0.053	-0.059	0.091	0.113	-0.026	-0.030
	(0.083)	(0.083)	(0.139)	(0.143)	(0.021)	(0.019)
GNfrontier	0.48400 ***	0.48400 ***	0.83700 ***	0.81400 ***	0.49700 ***	0.49600 ***
	(0.084)	(0.083)	(0.131)	(0.131)	(0.022)	(0.022)
GAfrontier	-0.01170	-0.01140	-0.21800	-0.20500	-0.05590 ***	-0.05610 ***
	(0.138)	(0.138)	(0.153)	(0.153)	(0.011)	(0.011)
age	0.001	0.001	0.002 **	0.001 *	0.000	0.000
	(0.004)	(0.004)	(0.001)	(0.001)	(0.000)	(0.000)
age2	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Dcoast	0.028 **	0.017 ***				
	(0.012)	(0.005)				
Ratio_foreign	-0.007	-0.032	0.005	0.003	0.005	0.004
	(0.034)	(0.077)	(0.014)	(0.014)	(0.004)	(0.008)
RNDi			0.164	-0.157	-0.041	0.054 ***
			(0.551)	(0.117)	(0.051)	(0.019)
exportratio			-0.008	0.027		
			(0.009)	(0.025)		
Dgroup			0.013	0.006		
			(0.015)	(0.016)		
Ndist_age	-0.007	-0.008	-0.004	-0.004 *	-0.001	0.000
	(0.012)	(0.012)	(0.003)	(0.003)	(0.001)	(0.001)
Ndist_coast	-0.028					
	(0.055)					
Ndist_foreign		0.047				-0.084
		(0.308)				(0.067)
Ndist_rnd			0.244		0.641	
			(0.962)		(0.464)	
Ndist_export				0.109		
				(0.107)		
Ndist_group			-0.176	-0.188		
			(0.116)	(0.115)		
Adist_age	0.009 *	0.009 *	-0.001	0.000	0.000	0.000
	(0.005)	(0.005)	(0.001)	(0.001)	(0.000)	(0.000)
Adist_coast	-0.009					
	(0.021)					
Adist_foreign		0.047				0.050 *
		(0.122)				(0.030)
Adist_rnd			-0.567		0.184	
			(1.172)		(0.323)	
Adist_export				-0.098		
				(0.060)		
Adist_group			0.051	0.063 *		
			(0.037)	(0.037)		
R-squared	0.150	0.149	0.227	0.228	0.277	0.275
Observation	2,816	2,816	1,601	1,601	22,981	22,981

Table 15. Estimation Result 5

	China b/se	Korea b/se	Japan b/se
Ndist	0.266 ***	0.312 **	0.162 ***
	(0.092)	(0.147)	(0.034)
Adist	-0.053	0.101	-0.033 *
	(0.083)	(0.139)	(0.019)
GNfrontier	0.48200 ***	0.82300 ***	0.49700 ***
	(0.083)	(0.130)	(0.022)
GAfrontier	-0.01140	-0.21200	-0.05680 ***
	(0.138)	(0.152)	(0.011)
age	0.001	0.002 **	0.000
	(0.004)	(0.001)	(0.000)
age2	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
Dcoast	0.029 **		
	(0.012)		
Ratio_foreign	-0.051	0.003	0.013
	(0.077)	(0.014)	(0.009)
dRNDi		0.149	-0.071
		(0.555)	(0.066)
dexportratio		0.023	
		(0.025)	
Dgroup		0.008	
		(0.016)	
Ndist_age	-0.007	-0.004	0.000
	(0.012)	(0.003)	(0.001)
Ndist_coast	-0.030		
	(0.055)		
Ndist_foreign	0.097		-0.139 *
	(0.307)		(0.074)
Ndist_drnd		0.218	0.688
		(0.965)	(0.556)
Ndist_dexport		0.124	
		(0.115)	
Ndist_group		-0.194 *	
		(0.115)	
Adist_age	0.009 *	0.000	0.000
	(0.005)	(0.001)	(0.000)
Adist_coast	-0.010		
	(0.021)		
Adist_foreign	0.065		0.040
	(0.124)		(0.030)
Adist_drnd		-0.526	0.271
		(1.179)	(0.359)
Adist_dexport		-0.092	
		(0.060)	
Adist_group		0.061	
		(0.037)	
R-squared	0.150	0.228	0.277
Observation	2,816	1,601	22,981

Table 16. Estimation Result 6

	China1	China2	Korea1	Korea2	Japan1	Japan2
	b/se	b/se	b/se	b/se	b/se	b/se
Ndist	0.266 ***	0.258 ***	0.343 **	0.311 **	0.154 ***	0.164 ***
	(0.092)	(0.092)	(0.145)	(0.146)	(0.032)	(0.036)
Adist	-0.053	-0.059	0.076	0.093	-0.029	-0.034 *
	(0.083)	(0.083)	(0.137)	(0.139)	(0.019)	(0.019)
GNfrontier	0.48400 ***	0.48400 ***	0.83900 ***	0.82300 ***	0.49700 ***	0.49800 ***
	(0.084)	(0.083)	(0.130)	(0.131)	(0.022)	(0.022)
GAfrontier	-0.01170	-0.01140	-0.21800	-0.21500	-0.05640 ***	-0.05680 ***
	(0.138)	(0.138)	(0.153)	(0.152)	(0.011)	(0.011)
age	0.001	0.001	0.002 **	0.001 *	0.000	0.000
	(0.004)	(0.004)	(0.001)	(0.001)	(0.000)	(0.000)
age2	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Dcoast	0.028 **	0.017 ***				
	(0.012)	(0.005)				
Ratio_foreign	-0.007	-0.032	0.005	0.004	0.005	0.005
	(0.034)	(0.077)	(0.014)	(0.014)	(0.004)	(0.008)
dRNDi			0.113	-0.154	-0.066	0.045 **
			(0.557)	(0.118)	(0.063)	(0.019)
dexportratio			-0.008	0.021		
			(0.009)	(0.025)		
Dgroup			0.012	0.007		
			(0.015)	(0.016)		
Ndist_age	-0.007	-0.008	-0.004	-0.004	0.000	0.000
	(0.012)	(0.012)	(0.003)	(0.003)	(0.001)	(0.001)
Ndist_coast	-0.028					
	(0.055)					
Ndist_foreign		0.047				-0.082
		(0.308)				(0.067)
Ndist_drnd			0.108		0.628	
			(0.980)		(0.541)	
Ndist_dexport				0.124		
				(0.115)		
Ndist_group			-0.177	-0.192 *		
			(0.116)	(0.115)		
Adist_age	0.009 *	0.009 *	-0.001	0.000	0.000	0.000
	(0.005)	(0.005)	(0.001)	(0.001)	(0.000)	(0.000)
Adist_coast	-0.009					
	(0.021)					
Adist_foreign		0.047				0.048
		(0.122)				(0.030)
Adist_drnd			-0.427		0.283	
			(1.188)		(0.359)	
Adist_dexport				-0.090		
				(0.060)		
Adist_group			0.052	0.062 *		
			(0.037)	(0.037)		
R-squared	0.150	0.149	0.227	0.227	0.277	0.275
Observation	2,816	2,816	1,601	1,601	22,981	22,981

6. Concluding Remarks and Implications for Future Research

Using firm-level data, this paper investigates the productivity convergence pattern for Japan, China, Taiwan and Korea. 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 for East Asian countries is not an easy task, the development of internationally comparable measures based on micro data could shed more light on the growth mechanisms underlying the so-called "East

Asian economic miracle," as well as the determinants and consequence of the heterogeneity of firms.

Our convergence analysis revealed that the pull from the national frontier was stronger in the case of Korea than that of Taiwan, China and Japan. In every country, lower-performing firms have been catching up to the national frontier at a faster speed than higher-performing firms, which provides evidence of strong convergence toward the national frontier. The Korean firms once reached to their national frontier, they continue to try to catch up toward the global frontier. In addition, the participation in corporate group contributes to the increase in the absorption capacity when the firms are trying to catch up to the global frontier, but it is not the case for catching up to the national frontier. In China, the engine of the knowledge creation is firms located in the trade-oriented coast and the firm's age has a positive impact on the catching-up to the global frontier.

In this study, we were not able to analyze the productivity of global frontier firms because comprehensive firm-level data were not available for the United States and for European countries. A comparison of the performance and/or competition between Asian frontier firms and frontier firms in developed countries from other regions would be another interesting research topic which deserves further investigation.

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