Is Digital Transformation (DX) Necessary for Industrial Complex? -Comparing Japanese petrochemical and chemical companies with global ones in TFP (Total Factor Productivity)-

Kazuya Inaba
Graduate School of Innovation & Technology Management, Yamaguchi University

1 Issues and Structure

Japanese industrial complexes have developed from their formative period in the 1950s to the present day when RING[1] projects and other projects have been implemented. The business model of industrial complexes is a unique business model that has historically developed in Japan[2]. One research question of this paper is whether this business model can be competitive internationally. In order to confirm this, it is necessary to compare Japanese and global petrochemical and chemical companies by some kind of index.

I have explained the development of Japanese industrial complexes from their historical background. From the aspect of economic rationality that make them possible to pursue cost leadership strategies and product differentiation strategies simultaneously, I have analyzed the economics of industrial complex theoretically, naming it the "economy of combination." But, without comparing competitiveness of Japanese complexes with that of others around the world in petrochemical and chemical industry by any index, it is difficult to determine whether it is or not an economically superior in business model. Therefore, I assume Total Factor Productivity (TFP), considering indicators that can be compared quantitatively[3]. I adopted TFP instead of financial or accounting analysis such as sales and other scale or profit margins. And I verify whether this model has the efficiency of production and manufacturing processes as well as capital and labor, and confirm whether there is the presence or absence of innovation (technological innovation). In this paper, I calculate TFP of Japanese companies in industrial complexes (mainly members of the Japan Petrochemical Industry Association) and that of petrochemical and chemical ones in other countries, and compare their

[1] RING (Research Association of Refinery Integration for Group-Operation) got support of the Ministry of Economy, Trade and Industry and was established in 2000. It has acted group-operation programs in Japanese industrial complexes.

[2] I have described them in these books: Kazuya Inaba, Kikkawa Takeo, and Sou Hirano (2013) "Industrial Complex Integration: The Revival of Japan's Petroleum and Petrochemical Industry," Chemical Daily; (2018) "New Era of Industrial Complexes: IoT, Hydrogen, and Business Cooperation," Chemical Daily.

[3] This study relies on M. E. Porter's arguments that "productivity" is important when determining international competitiveness, and that productivity focuses on "each industries and segments within industries" (Porter, M. E. (1990) “The Competitive Advantage of nations: with a new introduction”, New York: Free Press pp. 6-11).

international competitiveness in terms of TFP. Furthermore I propose to examine the need for DX.

2 Calculation of TFP (Total Factor Productivity) by Cobb-Douglas typed production function

In analyzing productivity, I assume a production function of Cobb-Douglas's type. This function considers capital and labor as factors of production. And TFP is a measure of productivity. It is a factor of variation in output that cannot be explained by inputs of capital and labor alone, and is often viewed as innovation in the broadest sense.

$$Y = A \times K^{(1-\alpha)} \times L^{\alpha}$$

Y is value added, A is TFP, K is assets, L is labor, and α is the labor share. α and $1-\alpha$ mean the elasticity of output with respect to labor and capital inputs. A is a concept that expresses the efficiency of capital and labor and is called TFP.

The Cobb-Douglas typed production function is a production function commonly used in macroeconomics[4], but I applied it to individual firms in this case. There are the same examples applied to individual firms for the study of profitability and productivity of small and medium enterprises[5]. However, it is necessary to make some modifications to apply this production function to individual firms in the petrochemical and chemical industries, which are defined as follows.

Value added (Y) = Operating income + Labor costs + Income taxes
Labor force (L) = Number of employees (consolidated)
Assets (K) = Property, plant and equipment (gross) or property, plant and equipment (net)
Labor distribution ratio (α) = Labor cost/Value added
Capital distribution ratio ($1-\alpha$) = 1 - Labor cost/Value added

We should generally compute by using a tangible fixed assets on a "gross" basis[6]. This

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4 A historical analysis of productivity transitions from macroeconomics is Gordon, R. J. (2016) "The Rise and Fall of American Growth", Princeton University Press.

5 Kenji Akamatsu (2013) "Trends in the Profitability and Productivity of Small and Medium Enterprises," Shoko Kinyu, October 2013, pp. 22-63.

6 To be precise, it should not be presented as "gross value" but rather as "replacement cost", which is "market value". Whether gross or net book value should be adopted technically when replacement cost data is not available.

is why it needs to include costs of land and machinery and equipment. However, I adopt both "gross" and "net". In many cases, firms announce either "gross" or "net" in their balance sheets. If we could compare their data, using both is the only choice to avoid reducing the number of firms. Therefore, in calculating TFP, I determine to describe two figures: TFP (1) (calculated by using gross tangible fixed assets) and TFP (2) (calculated by using net tangible fixed assets).

Data were gathered mainly from Refinitiv Eikon, a financial analysis data platform provided by Refinitiv, which is a subsidiary of the London Stock Exchange Group. However, in cases where the data were clearly erroneous (e.g., confusion of consolidated for non-consolidated figures), I corrected errors by checking their securities reports of relevant companies. The covered period is almost from 1994 to 2022, and years for which no data existed were left blank. The year-by-year data is presented as the end of the fiscal year (end of March) for Japanese firms, while as their annual results (end of December) for foreign firms. There are two main reasons for setting this period. I wanted to examine whether the development of ICT had an impact on TFP since the release of Windows 95 in 1995, and whether the RING project had an impact since the launch of the RING in 2000. I also tried to understand how the historical development of industrial complexes has affected the current TFP of their companies.

In comparing with many companies participating in complexes, I utilized the categories in the book of Takeo Kikkawa and So Hirano(2011) "The Age of Chemical Industry: Why can Japan overtake the world?", Chemical Daily. Based on their research findings, I used their classifications for petrochemical and chemical companies. The study divided styles of production into "specific" and "comprehensive" categories and product characteristics into "function-oriented" and "general-purpose product-oriented" categories. There are two axes and they classified the four categories. As a result, the four classifications for Japanese chemical industry are "Specific Functional Chemistry" ("specific" and "function-oriented"), "Global Commodity Chemistry" ("specific" and "general-purpose product"), "Comprehensive Functional Chemistry" ("comprehensive" and "function"), and "Global Comprehensive Chemistry" ("comprehensive" and " general-purpose product"). In addition to these four categories, global petrochemical and chemical companies were classified by region into three categories: "Europe and North America," "Korea and China," and "Others."[7] Here I compare the TFP of the four

[7] TFP estimation is usually done by each industry. Firms are categorized by production functions and classified the sample into groups. Each group must be classified because they have different production functions or because they have the same production function and different TFP. The treatment of diversified firms is controversial because it may conflict with assumption of similarity

categories of Japanese companies with that of three categories of global companies in petrochemical and chemical industry.

In calculating TFP for each company, I widely checked their profit and loss statements and balance sheets in Japanese and foreign ones, citing "Refinitiv Eikon." But in many cases, it was difficult to take data of the figures to calculate a Cobb-Douglas type production function, and it was impossible to calculate many foreign petrochemical and chemical companies, whose TFP was necessary for comparison in this study. In addition, among the Japanese companies that are members of JPCA (Japan Petrochemical Industry Association), there were many companies for which TFP could not be calculated due to a lack of data or because the data was not publicly available. Unfortunately, TFP for most U.S. companies could not be calculated. Because many U.S. companies included labor costs among "selling, general and administrative expenses" in their profit and loss statements, it is impossible to extract only labor costs. Their foreign companies for which TFP could not be calculated due to lack of data, considering it necessary for comparison, were Sinopec (China), Ineos (U.K.), Taiwan Plastic Group (Taiwan), Exxon Mobil (U.S.), Lyondell Basell Industries (The Netherlands), Braskem (Brazil), PPG Industries (U.S.), Solvay (Belgium), Praxair (U.S.), Arkema (France), Chevron Phillips Chemical (U.S.), Borealis (Austria), Huntsman (U.S.), Air Products & Chemicals (U.S.), Ecolab Inc. (U.S.), Ecolab (U.S.), Westlake Chemical (U.S.), Mosaic (U.S.), The Dow Chemical Company (U.S.), E.I. du Pont de Nemous and Company (U.S.) and others.

In cases where the calculated value clearly showed an abnormal number, these numerical figures were left blank. I regularly applied this rule to the year (degree) in which operating profit is negative. Each company sometimes has negative operating profit due to economic fluctuations or management failure (labor costs are often kept unchanged from the previous year), in which case the TFP value becomes extremely large, so it was treated as an error value[8].

The results of my calculations based on the above definitions and methods are presented in the graphs below (See from Figure 1 to Figure 28). I made two types of graphs for TFP (the whole) and TFP (individual firms) for each year (degree), and separated TFP (1) and TFP (2) (I drew four ones in total). In TFP (the whole) I showed

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of production function. In relation to this, it is inherently better to describe the statistics by comparing capital share with labor share.

[8] In addition to these cases, shocks of investment and restructuring also have a significant impact on the TFP value. It is an appropriate evaluation to exclude these firms from the sample only when conditions are bad, because this case probably result in overestimates in general. On the other hand, if we use single-year data for individual firms, the estimates will be highly volatile, so it is better to show a moving average over a period of about three years.

the average value (ave), median (median), and added standard deviation values to these average value up and down. You can understand the degree of variation by the length of the line segment of the standard deviation[9].

3 Conclusion

Comparing TFP (1) and (2) among the four categories of Japanese petrochemical and chemical companies, the graphs show that the "Global Integrated Chemicals" and "Global General-Purpose Chemicals" groups have relatively high TFP values. The "Global General Chemicals" group averaged 0.79 in TFP (1) and 1.27 in TFP (2) for each year, while the "Global General-Purpose Chemicals" group averaged 1.08 in TFP (1) and 1.30 in TFP (2) for each year. On the other hand, the "Specialty Chemicals" group averaged 0.56 in TFP (1) and 1.02 in TFP (2) for each year, and the TFP value was slightly lower than that of two groups of companies focusing on commodity products. The average TFP values for the "General Functional Chemicals" group are unreliable figures and useless because of the wide variation in TFP among the companies. Tosoh Corporation, in particular, has been benefited from recent market conditions and has achieved extremely high TFP values. I failed to analyze the "General Functional Chemicals" group and did not provide a clear picture of characteristics of the group as a whole, and it will be necessary to research each individual company separately.

After that, “the European and U.S.” petrochemical and chemical companies averaged 0.16 in TFP (1) and 0.26 in TFP (2) for each year, which are considerably lower than the figures of Japanese ones. On the contrary, the average annual TFP (1) and TFP (2) value of “the South Korean and Chinese” groups are 0.73 and 0.85, and indicates relatively high figures. These values of TFP are comparable to those of Japanese companies. “The Other” petrochemical and chemical companies group shows similar trends to those in Europe and the U.S., although their average annual TFP (1) is 0.27 and TFP (2) is 0.33, slightly higher than that of the European and U.S. group. However, the large variation between years suggests the need for analysis of individual companies.

The TFP values of (1) and (2) in Japanese petrochemical and chemical companies are higher as a whole than those of their foreign ones. However, there are several problems in concluding that the business model of industrial complexes in Japan is superior. To begin with, there is a question of whether TFP can be used to explain the superiority of the industry's international competitiveness. It is only the fact that Japanese petrochemical

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[9] In case of analyzing changes, it would be better to show the annual changes in histograms (by group, country, period, etc.) in usual TFP research papers rather than figures of TFP in individual firms.

and chemical companies have relatively high TFP values. An accurate judgment must be made by adding many other indicators of performance, including other theories and models, as well as financial, accounting, and patent information.

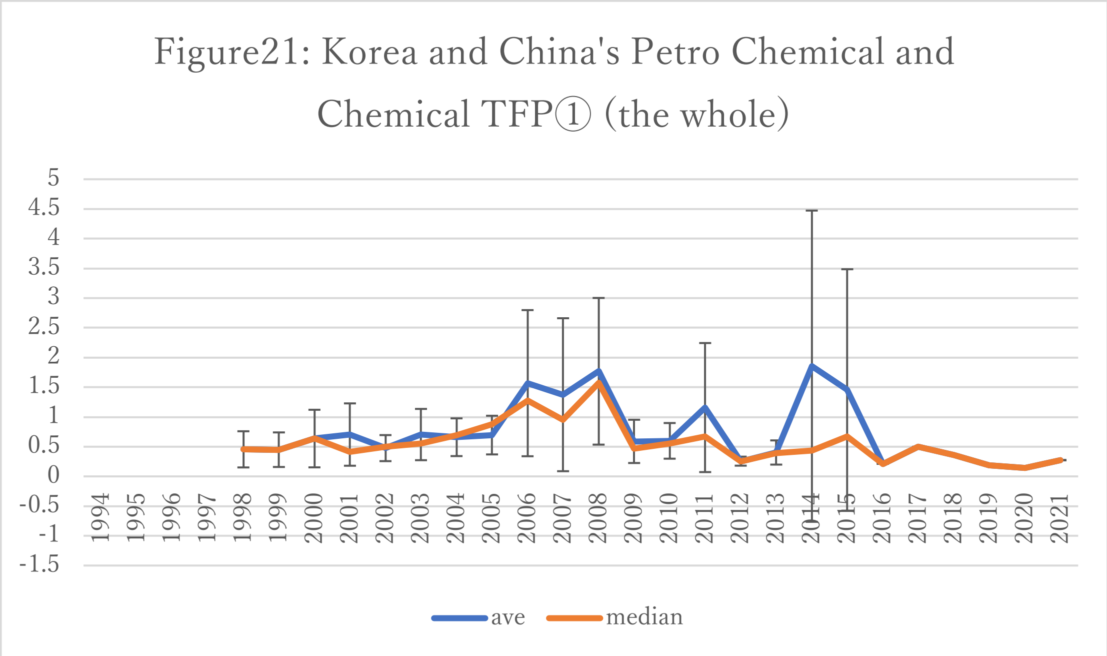
On the other hand, the analysis of TFP changes from 1994 to 2022 proves that the impact of the RING project, which started in 2000, is not clear, and that both Japanese and global firms show little significant change in TFP values, which remain flat in their line graphs. This suggests that the petrochemical and chemical industries in Japan and global are technologically mature and stagnant, with little innovation taking place over a long period of these years.

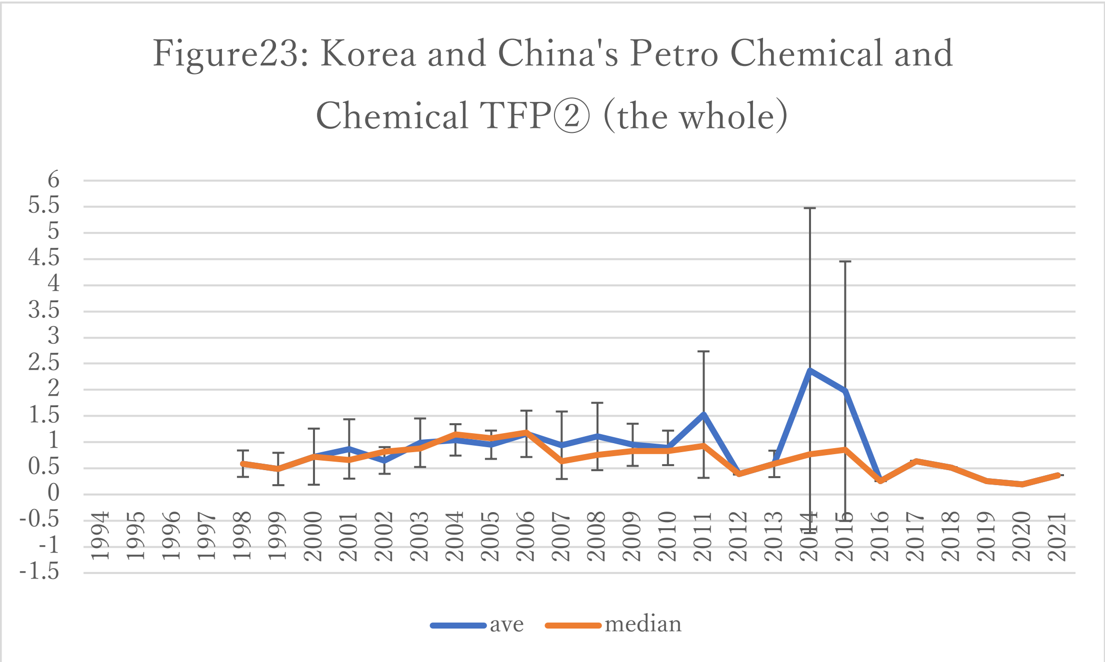
As a result, this industry is expected to continue to promote DX in order to increase profit margins by improving the efficiency of manufacturing processes. In addition, the industry is under pressure of greenhouse-gas reduction and must advance carbon neutral. So, it will be interesting to see how the impact of decarbonization's efforts will be reflected on TFP in the future.

In order to achieve sustainable development, industrial complexes must make strategic arrangements for the future. Business cooperation must be further promoted in order to increase the international competitiveness of industrial complexes. In order to further advance the sophistication of production, it is necessary to establish a business collaboration system using information and communication technology. Therefore, digital transformation is required for development of the industrial complex.

The complex is an industrial area where facilities for the petroleum, petrochemical, and chemical industries are concentrated from upstream to downstream. There are main equipments of naphtha crackers that produce basic raw materials such as ethylene and propylene, as well as plants of various sizes that manufacture a variety of products. As the word "Комбинат" implies combination, plants of different firms are connected to each other by piping, and they exchange raw materials, steam, and other resources. And in order to develop their integration further from now on, it is necessary to establish the organization to cope with changes of international competence and to design not only the combination of materials but also the system of information network.

The RING project has been playing a central role in the development of industrial complexes since the beginning of 2000, under the slogan called industrial complex's renaissance, overcoming barriers of capital, people, and geography. In order to develop and advance their collaboration further, the industrial complexes must be digital-transformed to improve productivity and efficiency. Japanese petroleum, petrochemical, and chemical companies depend on the assumption of importing raw materials and having disadvantages of small and medium-sized plants and dispersed domestic manufacturing factories, digital transformation will be the key to future development and innovation in the petroleum, petrochemical, and chemical industries.





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