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Who leads the IoT ecosystem? a Meta-frontier Approach

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Who leads the IoT ecosystem? a Meta-frontier Approach

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Abstract

As 5G has recently been commercialized, IoT ecosystem is rapidly growing. There are variety of participants in IoT ecosystem and they continue to innovate in their own way. This paper divided participants of IoT ecosystem into four sub-industries: service, network, platform, and device. This paper applies stochastic frontier analysis (SFA) and compare the efficiency among these sub-industries, which give us information who leads innovation in the sub-industry or between the sub-industries. After analyzing the financial data of Korean IoT companies from 2008 to 2018, this paper show that platform industry had led the innovation of IoT ecosystem in the early stage (until 2007) and after then, network and device industries have led the innovation, while service industry lags relatively behind other industries during the period. Moreover, the empirical findings collectively indicate that meta-frontier index values (TE, TGR and TE*) have all been continuously decreasing, which means that some of highly efficient companies in the IoT ecosystem have consistently maintained their dominance.

Keywords: IoT ecosystem; stochastic frontier analysis; meta-frontier analysis; IoT industry in Korea, innovation

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1. Introduction

IoT is considered as a core technology that forms a future society and is expected to be used in a variety of applications such as Manufacturing, Retail, Buildings, and Transportation (Gubbi et al., 2013). The market for IoT has seen an acceleration. Worldwide spending on the IoT is forecasted to reach 745 billion dollars and South Korea is expected to become one of the top five spenders on the IoT technologies in 2019 according to IDC (Torchia et al., 2018). IDC also expected the worldwide IoT spending will surpass the mark of 1 trillion dollars in 2022 maintaining a double-digit annual growth rate throughout 2017-2022. However, even though the concept of IoT has been proposed for a long time, it is assessed that actual use in real life is not yet as active as expected.

IoT research has been conducted at various levels, including service and business model, as well as technologies such as sensor and wireless connection. However, no research has yet been done to assess the overall IoT industry by an empirical approach. For the introduction and development of the Internet of Things, it is necessary to draw a landscape on the whole industry and figure out the bottleneck that impediment to development. In particular, the IoT industry has ecological characteristics in which various stakeholders and actors coexist, including hardware, software, platform, service, network, and security.

For the IoT industry to be activated, it is important to form a sustainable ecosystem consisting of various participants (Westerlund et al., 2014). This is because actors can work together to share resources, costs, and risks to make efficient use of them. Furthermore, the faster and larger the ecosystem is created, the more actors can be attracted to the ecosystem by network effect, resulting in co-evolution through collaborative competition.

Due to this, a competitive landscape of the IoT industry is changing from competition among firms in the industry to competition among ecosystems. Governments, including China and Japan, are implementing policies regarding the creation of ecosystems to secure global leadership through the development of IoT as a national industry. Global firms such as Google, Cisco, and IBM are also focusing on creating an ecosystem by providing open platforms and distributing their devices.

In this study, Korea's IoT industry is analyzed through a value chain and ecological perspective. Korea is suitable for the research because its ICT technology has been developed rapidly, and firms in IoT industries are actively competing for the IoT market in the same country. Especially, they are trying to create an ecosystem exploiting their domain knowledge and alliance.

To the best of our knowledge, this is the first research to analyze the efficiency among sub-industries of IoT and to use it to interpret the activities of businesses and industries from the ecosystem perspective. This paper contributes to the following areas: First, it can help establish strategies for business actors who want to create a healthy IoT ecosystem. Second, it can be used as a basis for the government's policy design to promote the IoT industry as a

national industry. Finally, we expect this research to be utilized and advanced in the academic area such as a health assessment of the ecosystem.

2. IoT Ecosystem

2.1 Architecture of IoT

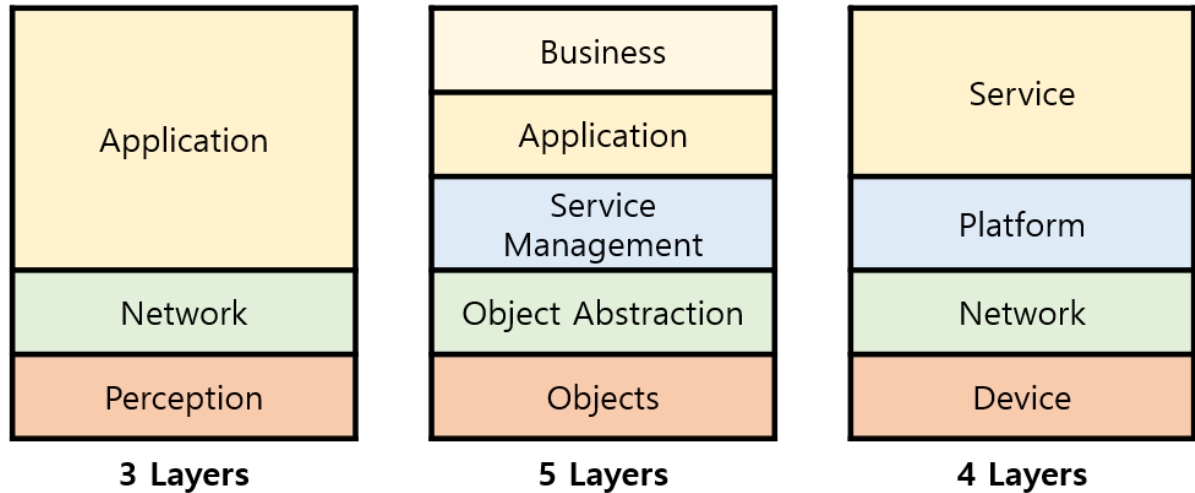
In order to portray the IoT ecosystem and understand the industry, it is necessary to investigate the architecture of it. In the most initial researches, IoT architecture is subdivided into three layers consisting of the *Perception*, *Network*, and *Application* layers (Wu et al., 2010; Yang et al., 2011), as described in figure 1. Perception layer represents the physical sensors of the IoT that aim to gather and process information to be transmitted through secure channels. Next, the Network Layer transfers data produced at the Perception layer through various IoT network protocols. Finally, the Application delivers data to end-user devices and provides the requested services.

In the recent study, a five-layer framework is proposed that divides more detailed roles than the three-layer model (Chaqfeh & Mohamed, 2012; Khan et al., 2012) consisting of the *Objects*, *Object Abstraction*, *Service Management*, *Application*, and *Business* layers as shown in figure 1. Likewise the *Perception* layer, *Objects* layer is a foundational layer that creates the data using the IoT physical sensors. *Object Abstraction* layer performs the role of data transmission as the *Network* layer. To achieve this goal, technologies like GSM, 3G, RFID, Bluetooth Low Energy, ZigBee, and Wi-Fi are exploited. By this layer, data can be transferred to the *Service Management* layer. In the *Service Management* layer, services are paired with requesters based on their addresses and names. Data from *Object Abstraction* layer is processed in this layer, processed data is delivered to the required services over the network. *Application* layer carries out the service requested by users and provides applications including smart homes, smart buildings, smart factories, transportation. Finally, the *Business* layer manages overall IoT system services and activities. This layer also undertakes tasks such as design, analysis, implementation, evaluation, monitoring.

In Korea, statistical surveys of the domestic IoT industry are carried out to investigate its competitiveness and foundation. It is provided for government policymaking and corporate management. In the survey, the IoT industry is subdivided into four categories based on the IoT architecture and its role: *Device*, *Network*, *Platform*, and *Service*. *Device* layer (industry) includes functions (products) to generate, collect, and deliver information and functions that can operate on their own. *Network* layer provides communication infrastructure to transmit the data that the device collected to people, platforms, or other devices. *Platform* layer is responsible for processing the collected data, as well as for interworking services and applications. Finally, *service* layer provides services that are applied with IoT technology and performs functions such as management and control of devices that are connected to IoT.

Although the names of the layers are different, as each layer in a 5 layer model is matched with 3 layers, 5 layers and 4 layers (category) can be matched to each other based on its functions. In this study, analysis is conducted setting subclasses as 4 layers.

Figure 1 IoT architectures

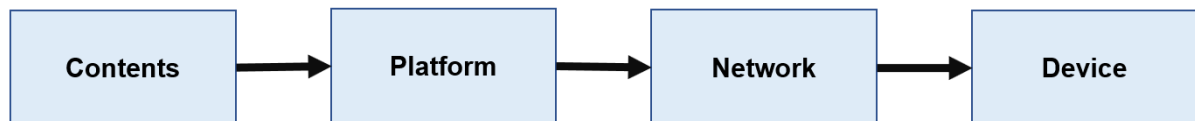


2.2 Value chain & IoT ecosystem

The concept of the value chain was developed and popularized Michael Porter (Feller, 2006; Luh, 2008). A value chain is a whole process of meeting the needs of a customer by closely connecting the activities of a company that value the customer and the production process that enables the activity (Porter, 1985). According to his theory, the business unit is the appropriate level for constructing a value chain, not corporate or groups.

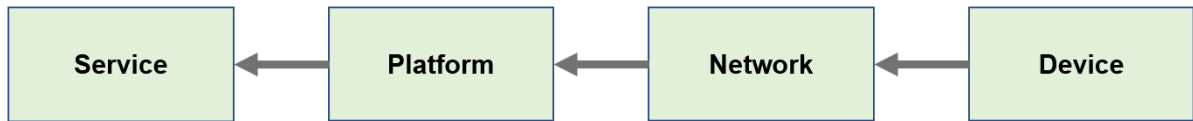
However, the process of value creation throughout collaborations and the linkage between multiple firms has more commonly become called the value chain in the present era. One of the most famous theories on the industry level is the CPND model. CPND is a horizontal value chain that transports value with Contents(C)-Platform(P)-Network(N)-Device(D) between content producers and users in ICT (Information and Communications Technology) industry (Jung, 2012) as described in figure 2. In the concept of CPND, the core functions are scattered in each industry and it can be integrated by the connection among CPND to improve the efficiency of industry (Choi, 2014)

Figure 2. CPND value chain in ICT industry



However, as discussed in section 2.1, the architecture of IoT consists of Device(D), Network(N), Platform(P), and Service(S) in order from a data flow perspective (figure 3). When CPND's *contents* industry is said to match the *service*, this is quite the opposite of CPND's value chain structure as seen earlier.

Figure 3. System architecture of IoT in data-stream



At the business level, the ecosystem concept was first introduced by Moore(1996). According to its definition, the ecosystem is a concept that includes "the network of buyers, suppliers and makers of controlled products or services" and socio-economic environment, similar to natural ecosystems. Later, Iansiti & Levien(2002) and others argued that unlike the natural ecosystem, the actors not only aim to survive but also to increase value through cooperation, competition and innovative activities centered on the dominant keystone.

In the traditional value chain concept, value arises in the process of producing and distributing products or services by a firm. From an ecosystem perspective, however, the performance and survival of individual companies are not only in their own competitiveness but also in line with the entire ecosystem. Therefore, the business ecosystem also takes into consideration the sources of assets, related firms, innovation, technology, competitors and customers that give feedback on the development of products and processes, and regulations by government agencies.

This study analyzes the IoT industry from a value chain and ecological perspective. We analyze and compare the efficiency of firms, because the results of activities in the ecosystem, as well as the value creation of companies, are shown by the efficiency of the companies and the sub-industry to which they belong. The following section introduces the methodology for the analysis.

3. Methodology

3.1 Stochastic frontier analysis & Meta-frontier analysis

In this paper, we use stochastic frontier analysis (SFA) to measure the technical efficiency (TE) of a firm. The production function of each year is estimated separately, and then the movement of the efficiency is examined with time. For the model, the original cross-sectional model is used (Aigner, Lovell, and Schmidt, 1997). The production function used in this study is as follows:

$$Y_i = f(x_i, \beta) e^{V_i - U_i}, \quad i = 1, 2, \dots, N \quad \text{Eq. (1)}$$

where Y_i is the output of firm i , f is the production function, x_i is a firm i 's input vector, β is an unknown parameter. V_i is a random variable that follows a normal distribution of regression equation which is independent and identically distributed, and U_i is the inefficiency follows a half-normal distribution

From Equation (1), the technical efficiency of firm i is calculated as Equation (2):

$$TE_i = \frac{Y_i}{f(X_i, \beta) e^{V_i}} = e^{-U_i}, \quad i = 1, 2, \dots, N \quad \text{Eq. (2)}$$

where TE_i is the technical efficiency of firm i .

In general, TE is an analysis of efficiency within the homogeneous industry. To compare the efficiency between different industries operating different types of businesses, meta-frontier analysis is proposed (Battese and Rao, 2002). This study defines the meta-frontier production function as follows (Battese, Rao, and O'donnell, 2004):

$$Y_{it}^* = f(x_{it}, \beta^*) = e^{x_{it}\beta^*}, \quad i = 1, 2, \dots, N, \quad N = \sum_{j=1}^R N_j, t = 1, 2, \dots, T, \quad \text{Eq. (3)}$$

β^* is the unknown vector of the meta-frontier production function. It is necessary for β^* to satisfy the condition $x_{it}\beta^* \geq x_{it}\beta_{(j)}$, because the meta-frontier production function should envelop all the group frontier production functions,

$$s.t. \quad x_{it}\beta^* \geq x_{it}\beta_{(j)} \text{ for all } j = 1, 2, \dots, T \quad \text{Eq. (4)}$$

If we assume that f is in the form $e^{x_{it}\beta_{(j)}}$ for simplicity, Equation (1) can be rewritten as Equation (5):

$$Y_{it} = e^{-U_{it(j)}} \times \frac{e^{x_{it}\beta_{(j)}}}{e^{x_{it}\beta^*}} \times e^{x_{it}\beta^* + V_{it(j)}} \quad \text{Eq. (5)}$$

We can derive Equation (6) from Equation (5).

$$\frac{Y_{it}}{e^{x_{it}\beta^* + v_{it(j)}}} = e^{-U_{it(j)}} \times \frac{e^{x_{it}\beta_{(j)}}}{e^{x_{it}\beta^*}} \quad \text{Eq. (6)}$$

On the right-hand side of Equation (6), TE is defined as the first part in Equation (2). The second part is defined as the technology gap ratio (TGR). TGR represents the ratio between the frontier and the meta-frontier for each group.

$$TGR_{it} = \frac{e^{x_{it}\beta_{(j)}}}{e^{x_{it}\beta^*}} \quad \text{Eq. (7)}$$

The left-hand side of Equation (6) is called the meta-frontier technical efficiency (TE*). TE* represents the technical efficiency of a firm i in the meta-frontier.

$$TE_{it}^* = \frac{Y_{it}}{e^{x_{it}\beta^* + v_{it(j)}}} = TE_{it} \times TGR_{it} \quad \text{Eq. (8)}$$

Meta-frontier parameters can be estimated in both ways: linear programming (LP) and quadratic programming (QP). LP minimizes the sum of the difference between the estimated meta-frontier and the group frontiers, and QP minimizes the sum of the square of the difference between the estimated meta-frontier and the group frontiers. As the difference of estimation results by two methods are marginal, we only show the estimation results with QP for the readability.

3.2 Data collection & descriptive statistics

We divide the IoT industry into four sub-industries as investigated in section 2.1: *Device*, *Network*, *Platform*, and *Service*. IoT industry is subdivided as shown in Table 1. For each subclass, Korea Standard Industrial Classification (KSIC) code is allocated which means a standard code that classifies industrial activities that are primarily carried out by a production unit (company, enterprise, etc.).

Although the IoT sub-industry and the industry code is matched, generally, firms' revenue is not generated in only one area by the nature of IoT industry. However, since KSIC code is assigned based on the main industry in which the most of firm's sales comes from, each firm is most related to the allocated industry.

Table 1. Subclass of IoT industries

Sub-industry	KSIC (korea)	Description
Device	2611	Manufacture of Electronic Integrated Circuits
	2629	Manufacture of Other Electronic Components, Except Semiconductor and Electronic Integrated Circuits
	2631	Manufacture of Computer
	2632	Manufacture of Storage Units and Peripheral Equipment
	2642	Manufacture of Broadcasting and Wireless Telecommunication Apparatuses
	2651	Manufacture of Television, Video and Other Audio Equipment
Network	2641	Manufacture of wire communication apparatuses
	6121	Wired Telecommunications
	6122	Wireless Telecommunications
	6123	Satellite Telecommunications
	61291	Telecommunications Resellers
Platform	6201	Computer programming Services
	62021	Computer System Integration Consultancy and Establishment Services
Service	5822	System and Application Software Development and Supply
	61299	Other Telecommunications n.e.c.
	62022	Computer Facilities Management Services
	6209	Other Information Technology and Computer Operation Related Services

We acquired data from KIS-VALUE, the largest database for enterprise information in South Korea. KIS-VALUE provides financial and accounting information for about 20,000 companies dating back to 1980. As the term ‘Internet of Things’ is coined in 1999, only data from 2000 to 2018 are analyzed in this study. To measure the efficiency of each firm, net sales (Y) was used as an output variable, and the number of employees (L), total assets (K), and operational cost (M) were used as input variables. Sample missing any of the variables are excluded from the analysis; finally, 1,863 samples in the *Device* industry, 318 samples in the *Network* industry, 481 samples in the *Platform* industry, 1,110 samples in the *Service* industry are used in this study.

Table 2. Descriptive statistics

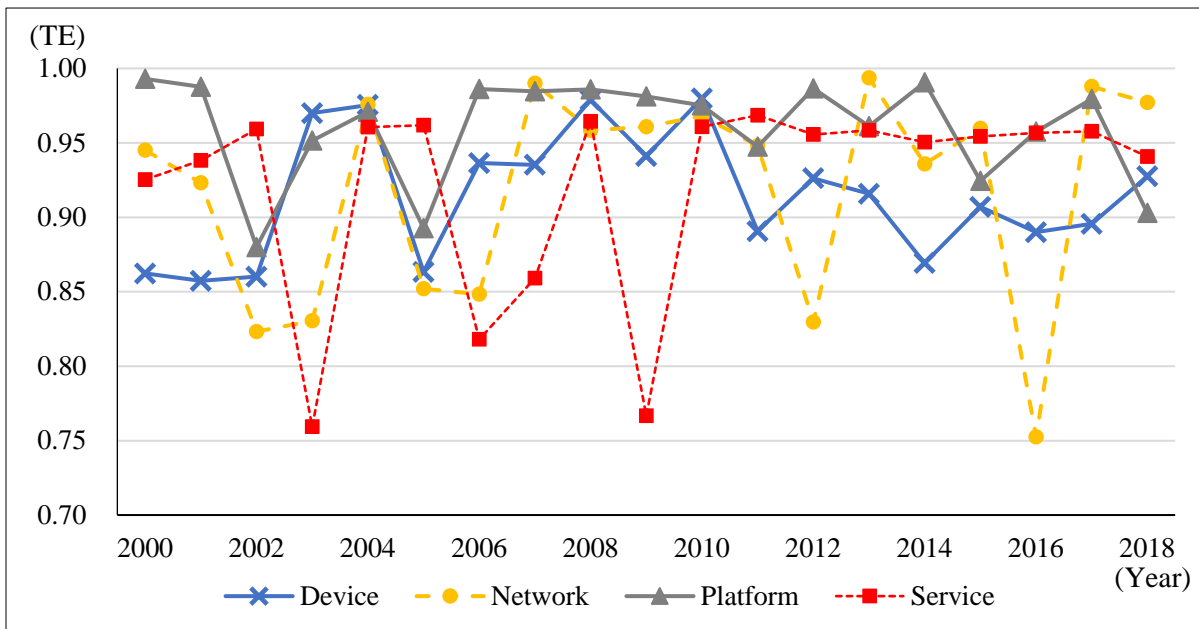
Industry	# of samples	Avg. of lnY	Avg. of lnK	Avg. of lnL	Avg. of lnM
Device	1,863	24.6897	24.1249	5.0155	24.4441
Network	318	25.3181	25.0315	5.4542	24.4631
Platform	481	24.9721	24.1096	5.3658	24.7640
Service	1,110	23.5849	23.2965	4.5700	22.9077

4. Analysis Results

Technical efficiency (TE) is an indicator for each firm's efficiency against the maximum efficiency of the industry, the increase in TE means that efficiency of the firms in certain sub-industry have increased. On the other hand, a sharp decline in TE means that only a few firms' efficiency has increased dramatically due to its innovations. Therefore, the fluctuation of TE can be interpreted as the active activity of innovation in the industry. Conversely, stagnant TE without significant changes means that the production functions of the firms in the group are analogous to the one from last period.

TE of *service* before 2010 and *network* is fluctuated the most. The service industry has shown stability since 2010, while the network industry is still showing great amplitudes. The device industry also has a rather small amplitude but steady ups and downs. Platform industry showing relatively little variation. In conclusion, innovations such as the development and release of new products are taking place in the network and device industries, and the service industry has remained stagnant since 2010 and the platform industry has remained unchanged.

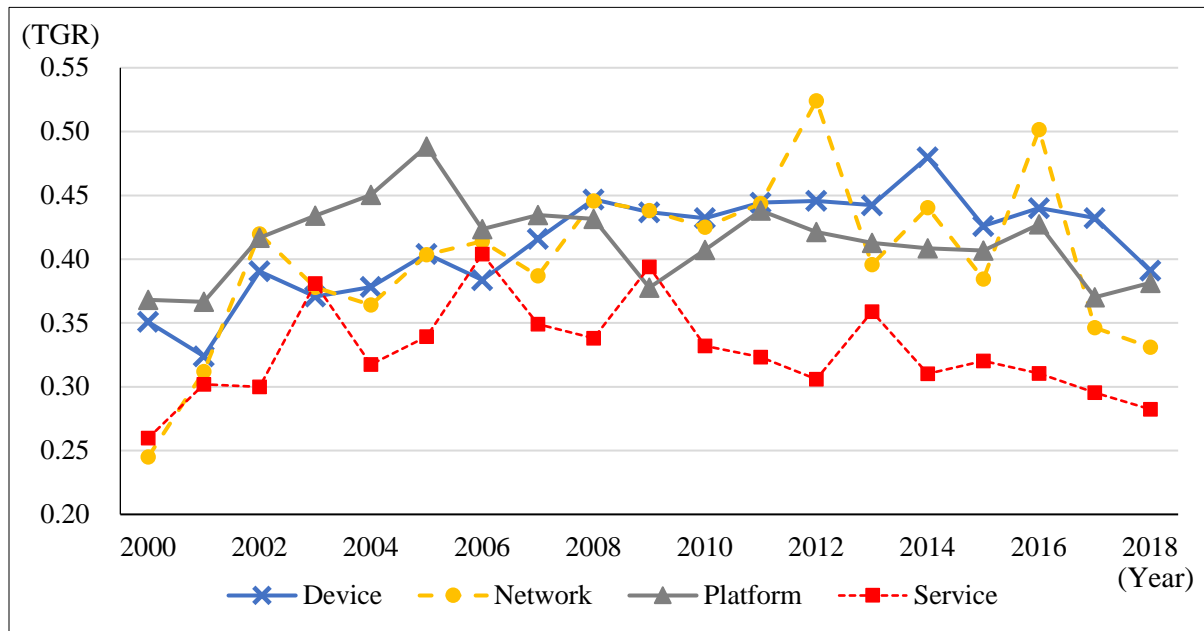
Figure 4 Change of TE in IoT industries



The ratio of the corresponding IoT industry frontier function to the meta-frontier function (TGR) is the ratio of the meta-frontier (maximum efficiency that the whole industry can produce) and the group frontier (maximum efficiency that the group can produce), which is a comparison index for the maximum efficiency per group. The low level of this indicator in a sub-industry means that the efficiency of it is relatively low than the maximum efficiency of the IoT industry, and the overall growth potential of the sub-industry is large. In addition, the increasing TE^* means that innovation is more active than other groups, and the lower TE^* compared to the higher TGR means that there is greater growth potential than other groups.

From 2000 to 2007, the platform industry's TGR was the highest, apparently leading the growth of the IoT ecosystem. The device and network industry have maintained its highest level since 2008 with a steady increase in TGR since 2000. In the device industry, smartphones have been introduced in earnest since 2007, leading to the growth of the ICT market as a whole, and the network industry has also grown rapidly with the increase of wired and wireless Internet and mobile communication subscribers. On the other hand, for the service industry, the TGR has remained relatively low compared to other sub-industry.

Figure 5 Change of TGR in IoT industries

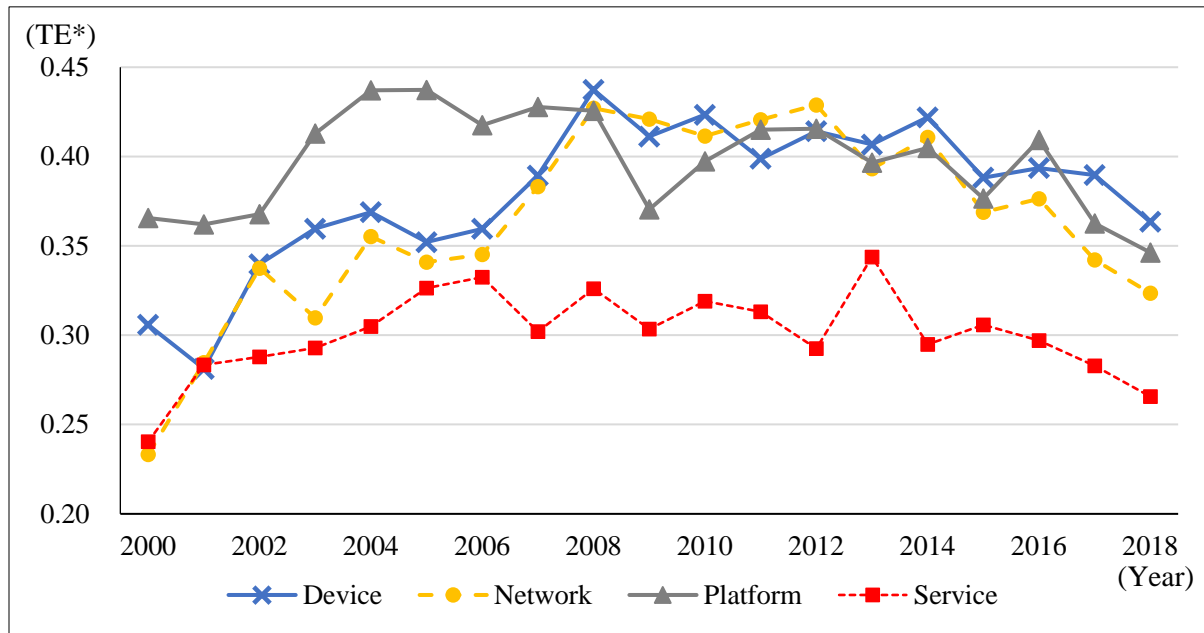


The mean of efficiency against the Meta-Frontier (TE^*) is the average efficiency of the companies in the IoT industry as a whole and is an indicator of how much efficiency the sub-industry is showing in the entire IoT industry at each point in time. Thus, the overall rise of TE^* means that with the rise of Metapronty, all companies in sub-industry are also

continuously growing. Conversely, the decrease in TE^* means that some companies in the entire IoT industry are leading innovation, but others are struggling to keep up with it.

In particular, both TGR and TE^* have been on the decline in recent years, meaning the efficiency of some companies is consistently greater than that of most companies. This can be interpreted as global trends in the IoT industry mentioned in Section 1, some companies including Google, Samsung, LG, and Cisco are leading the IoT industry by creating an ecosystem that makes them keystone.

Figure 6 Change of TE^* in IoT industries



5. Concluding Remarks

Our results contribute to the empirical body in the research stream of the IoT value chain and ecosystem by analyzing the efficiency of IoT sub-industries and comparing them between heterogeneous industries. Analysis has found that TE , TGR and TE^* values have all been decreasing continuously, which means that some highly efficient companies in the IoT ecosystem have consistently maintained their dominance. This results reflects actual circumstances in that global conglomerates such as Google, Samsung, LG, and Cisco are creating their own ecosystem and to be a keystone player, thus domineering the IoT industry, while, other participants are still lags behind.

In addition, fluctuation of TE mainly appears in the *network* industry and in the *service* industry before 2010, which means that innovative activities in the industry are actively taking place. South Korea's network industry is very fast in technological development, especially in the mobile communications sector, and government policies are also changing frequently due

to citizens' demands. In the IoT service industry, however, the recent release of new services or technologies has been stagnant. For the platform industry, the change of TE appears relatively small, reflecting the industrial characteristics that the effects of 'economy of scale' on efficiency are very large and that imitation is difficult to occur.

Finally, the TGR and TE* of the *device* and *network* industry has been increasing since 2000 and has remained the highest level of sub-industries since 2008. This can be interpreted as device and network is the industry that leading the growth of the IoT industry. This trend since 2008 can be explained with an introduction of the smartphone. The launch of smartphones has made more diverse service available to consumers. As a result, demand for development of communication technology has increased and the development of communication technology has formed a positive feedback loop, which in turn drives innovation in devices.

Although this paper provides new findings of competition landscape of IoT ecosystem, it is not free from some limitations. First, the corporate financial data we used to calculate efficiency may be related other services rather than IoT only, because a company can provide different services simultaneously. Thus the efficiency of each sub-industry may not reflect pure values of IoT related services. Second, because KIS-VALUE is providing the data for firms with external audits, a large number of small and medium-sized entities included in the industry are excluded from the analysis. These firms would possibly deliver other hidden interactions within and between industries that the current study does not find. Third, because we only analyze ICT firms in South Korea, the external validity of our study is limited. ICT industry is advanced in South Korea and the competitiveness is high in ICT hardware, driven by due to the global electronic companies such as Samsung and LG, the cost of manufacturing and building IoT commodities might be relatively lower than in other countries. Therefore, it is recommended to perform the analysis using data of different countries for future research.

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