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GLOBAL DIFFUSION OF INTERESTS TO INTERNET OF THINGS OVER WEB SEARCH TREND DATA

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Abstract. *As a solution to low-growth structure of the world economy, governments, corporations, universities and researchers in each country are actively pursuing related research and investment with an interest in innovation using the Internet of Things (IoT). For technological innovation to be successful, not only the technology itself should be advantageous, but also the popular acceptance of products and services using that technology is important. Therefore, it is necessary to systematically study the general public's interest to IoT, and to find strategic measures for the successful diffusion of the technology. This study has analyzed Google Trends data to track people's interest to the IoT. First, the global interest of the IoT has been surveyed by correlation analysis. Second, the trends of global interest have been examined by dynamic correlation analysis. Third, several leading countries for such trends are identified by Granger causality test using vector autoregressive model, and the impacts of their influences are examined by impulse-response function. The results of this study are expected to be useful for future innovation research and policy development using the IoT, and will be helpful for establishing innovation strategy at the global scale.*
Keywords: Global diffusion, Internet of Things, Technology adoption, Web search data

1. **Introduction.** As a solution to low-growth structure of the world economy, governments, corporations, universities and researchers in each country are actively pursuing technological innovations that have potentials to boost their industries. The Internet of Things (IoT) is widely considered as one of such potential technologies. In order for technological innovation to be successful, not only the technology itself should be advantageous, but also the general public's adoption of products and services using that technology is important. So understanding users' adoption of new technology and its derived products is very critical. Meanwhile, globalization has changed the world into nearly one large market, and made it almost unthinkable to separate one nation's economy or industry from that global market. Many multinational enterprises even exert their effort to exploit network externalities from this global market (or from this global connectivity). In this globalized environment, managerial decisions should be done on the global scale. From the perspective of technology adoption, managerial issues are such as 'which country to enter first', 'to which country to expand', and 'when to exit from a country'. To answer these questions, studying and understanding users' adoption of new technology in the global scale are important. And it also requires understanding diffusion of new technology with global dynamics of each nation. To track such technology diffusion, general

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public's interest on that technology needs to be assessed. In this study, authors propose an approach using Google Trends data to evaluate such dynamics of general public's interest to innovative technology at the global scale. Authors are going to demonstrate the approach by giving a specific case, IoT, so that the proposed method in this article will be applied to other new technologies.

In Section 2, studies on technology adoption and web search trends are briefly summarized as related researches. In Section 3, evaluation for technology adoption capability of each selected country has been done by observing the level and change on the interest of public in each country. The global diffusion of interest in the IoT is studied in Section 4 through the static correlation analysis and its changing trend through the dynamic correlation analysis. The leading countries for the interest on IoT are identified by Granger causality test using vector autoregressive model. And the degree of impact of a leading country on the other countries is examined by looking at impulse-response function. Finally, conclusions and implications will be given in Section 5.

2. Related Researches.

2.1. Technology adoption. Research on users' adoption of new technologies has been evolving for decades. Diffusion of Innovation (DOI) [1,2], Technology Acceptance Model (TAM) [3], Unified Theory of Acceptance and Use of Technology (UTAUT) [4] were proposed and developed to understand users' behavior [5,6]. While TAM and UTAUT focus on behavioral attitude, the DOI focuses on longitudinal changes of diffusion rates and the sequence in which adoption occurs [5]. Beal and Bohlen [1] is the first to note differences in adoption timing for technological innovations across countries [7]. Table 1 shows these adopter timing categories as well as Rogers' [2] with description for the global ICT (Information and Communication Technology) adoption context. Beal and Bohlen [1] also categorize five chronological stages in the diffusion process which are awareness, interest, evaluation, trial, and adoption stages. These categories could help management to evaluate adoption capabilities of countries and to build priority of entry or penetration. Since Beal and Bohlen [1] and Rogers [2] proposed the framework, empirical studies [8-11] have tried to measure stages of countries. Few studies, however, have focused on the changing trends of interest which are important to understand global dynamics of each nation, since sales data is often unavailable or difficult to gather for new technology.

2.2. Web search data. Google, which provides search services, operates a global service that provides search volume data called Google Trends. Google Trends calculates how much a particular search term is searched relative to other search terms and provides it in the form of an index. The change in the search volume relative to a particular search term indicates a change in the interest of the general public in a particular search term,

Table 1. Adopter timing categories in the literature

Beal and Bohlen [1]	**Rogers [2]**	**Description for the global ICT adoption context**
Innovators	Innovators	The first countries to adopt a new ICT
Early adopters	Early adopters	Countries adopting new ICT immediately after the innovators
Early majority	Early majority	Countries beginning to adopt ICT at the same times as majority
Majority	Late majority	Countries adopting ICT later with majority of other countries
Non-adopters	Laggards	Non-adopters and countries adopting much later than majority

so that by analyzing this index, the general public's interest can be indirectly understood. For this reason, recent research using Google Trends is actively being carried out. For example, Preis et al. [12] used this data to analyze participants' behavior in the stock market. Bordino et al. [13] and Choi and Varian [14] used this data to measure the predictive power of stock prices and sales. Ginsberg et al. [15] and Goel et al. [16] studied influenza forecasting using an Internet search service.

So this study analyzes technology adoption using Google Trends data. Meanwhile, Jun et al. [17] attempt to demonstrate that search traffic accounted for the trends of technology adoption over the full life-cycle very accurately. Jun et al. [17] compared the trends of changes in the life-cycle and compare aspects of the search traffic exhibited by both United States of America and Korean consumer over various products. Jun et al. [17] could help understand global adoption of new technology. However, Jun et al. [17] could not consider the interaction among countries in evolution of technology adoption. This study attempts to demonstrate new approach so as to consider the interaction among countries in evolution of technology adoption.

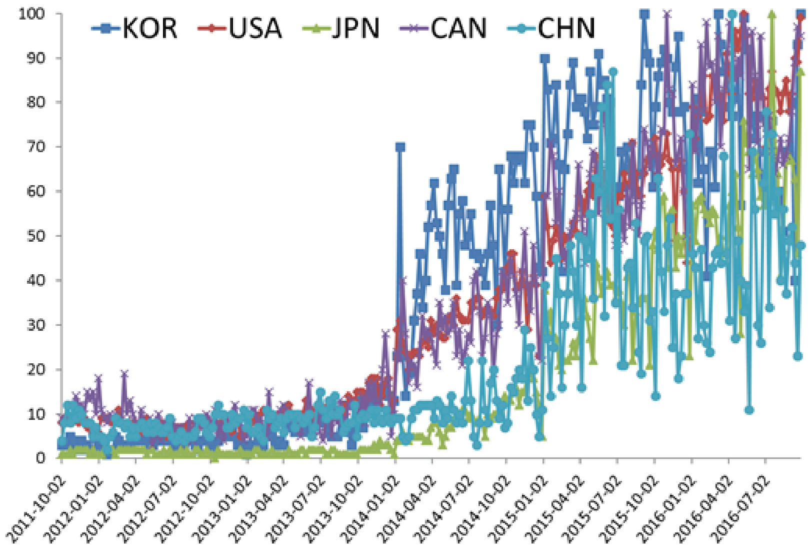
3. **Evaluating Technology Adoption Capabilities.** Since interest stage is a necessary stage in the process of technology adoption, by observing the level and change on the interest, adoption capabilities of each country for certain technology (or product) could be inferred. Authors have assumed that web search traffic can be a possible measure for such interest of the general public. Google Trends offers a ranking for top 25 countries in terms of how much portions of searches for a particular query has occurred within each corresponding country. We can compare relative technology adoption capabilities of countries indirectly by examining the rankings. Table 2 shows the rankings for search term IoT as of 25th September, 2016. In the case of the Republic of Korea, it occupies the first place in the search volume for the IoT. Taiwan is the second, and China is the third.

Table 2. Google's search volume ranking for IoT

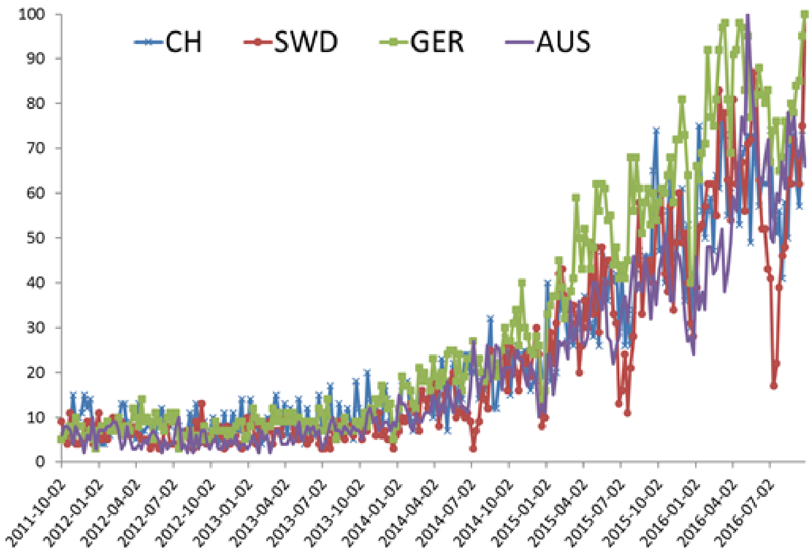
1	Korea, Rep.	6	Japan	11	Ireland	16	Netherlands	21	New Zealand
2	Taiwan	7	Hong Kong	12	Israel	17	Malaysia	22	Belgium
3	China	8	Finland	13	Swiss	18	USA	23	Germany
4	Singapore	9	Vietnam	14	U Arab Emirates	19	South Africa	24	United Kingdom
5	India	10	Italy	15	Sweden	20	Norway	25	Austria

This study examined trend of search traffic to evaluate changing trend of interest in IoT and adoption potential of each country for the technology. Figure 1 shows Google Trends index on the Republic of Korea (KOR), United States of America (USA), Japan (JPN), Canada (CAN), China (CHN), Switzerland (CH), Sweden (SWD), Germany (GER), and Australia (AUS) for search term IoT during the period, 2nd October 2011 $\sim$ 25th September 2016. All countries' indexes increase together since 2nd December, 2013 although some deviations exist. It implies that base for technology adoption is being constructed.

4. **Global Diffusion of Interest for IoT.** Throughout the world, the public can share their interest in advanced technologies such as IoT, augmented reality, additive manufacturing, and wearable devices. So interest of people in a country could evolve and raise interest of the others, collectively. This study demonstrates an approach to recognize the dynamics and interactions among countries during technology adoption. In Section 4.1 and Section 4.2, authors have examined the global relationship of interest in IoT through the static correlation analysis and its changing trend through the dynamic correlation analysis. In Section 4.3, the leading countries on the interest in IoT have been found by



(a) KOR, USA, JPN, CAN, CHN



(b) CH, SWD, GER, AUS

FIGURE 1. Search query trends in each country for IoT

Granger causality test using vector autoregressive model, and the scale is also examined by impulse-response function [18,19].

4.1. **Static correlation analysis.** In order to see how much the interests of a country actually are related to the others, authors have conducted static (Pearson) correlation analysis and summarized the results in Table 3 for search term IoT using Google Trends data collected weekly during the period, 2nd October 2011 $\sim$ 25th September 2016. Augmented Dickey-Fuller unit-root test was performed to confirm the stability of the time series [20]. As a result of the test, the time series data to be used are identified in the unstable time series of I (1) which needs to be transformed for stability of time series [20]. Thus, the stabilized time series by the first order difference is used in the static correlation analysis and the subsequent analysis. Of the 36 correlation coefficients, total 21 (58.33%) were statistically significant at the significance level of less than 10%. This implies that there exists a mutual relationship of interest among countries.

Table 3. Results of static correlation analysis on search queries in each country for IoT

	KOR	USA	JPN	CH	SWD	GER	CAN	AUS	CHN
KOR	1.00								
USA	0.21***	1.00							
JPN	0.25***	0.33***	1.00						
CH	0.20***	0.10	0.01	1.00					
SWD	0.14**	0.07	0.08	0.29***	1.00				
GER	0.30***	0.41***	0.20***	0.29***	0.33***	1.00			
CAN	0.11*	0.38***	0.10	0.00	0.11*	0.20***	1.00		
AUS	0.14**	0.23***	0.27***	0.01	0.11*	0.32***	0.11*	1.00	
CHN	0.02	−0.06	0.09	0.07	0.02	−0.05	0.05	−0.06	1.00

Significance level: 1%***, 5%**, 10%*

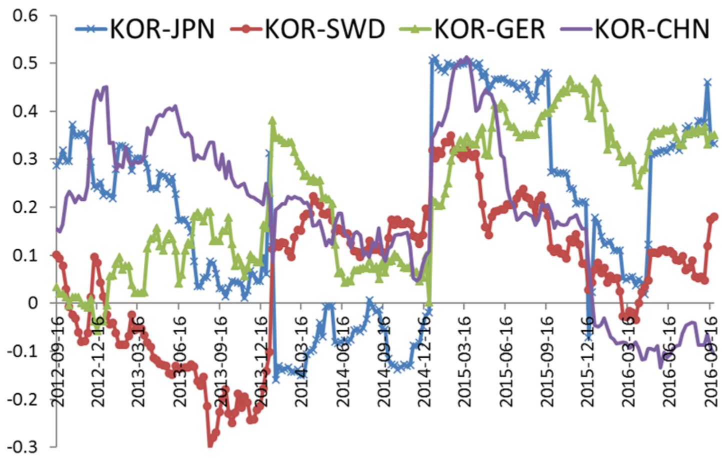


Figure 2. Dynamic correlations for each pair of countries

4.2. **Dynamic correlation analysis.** Dynamic correlation analysis was conducted to analyze how the sharing of interest in IoT has changed. That is, the time window was set to 50 weeks, and the Pearson correlation coefficient during that time period for each pair of the countries was calculated, and the coefficient was continuously calculated while moving for one week for each pair of countries in parallel. Figure 2 shows the dynamic correlation coefficient between Korea and some countries saying that Japan, Sweden, Germany and China respectively. In case of Korea, correlations with Japan and Germany seem to have a tendency to strengthen, while correlations with China and Sweden seem to have a tendency to weaken. In order to confirm whether the correlation between each pair of countries is strengthening or weakening, regression analysis using Equation (1) has been performed with dynamic correlation coefficient $\rho_{x,y}(t)$ as dependent variable and time trend t as explanatory variables. Positive β value means strengthening correlation, which indicates the growth-pattern between two countries is analogous although there exist some time lags.

$$\rho_{x,y}(t) = \alpha + \beta t \tag{1}$$

Table 4 summarizes the estimated coefficient β and the significance level of it in the regression analysis for all pairs of countries. About 86.1% are statistically significant at a significance level of less than 5%. And 83.9% of them have a positive β value, which implies that the majority of countries show growing similarity in their interest patterns in the long-term period for IoT.

TABLE 4. Results of trend analysis on dynamic correlations (β estimates)

	KOR	USA	JPN	CH	SWD	GER	CAN	AUS	CHN
KOR	1.00								
USA	0.27***	1.00							
JPN	0.07***	0.32***	1.00						
CH	0.08***	−0.02	0.01	1.00					
SWD	0.12***	0.00	0.13***	0.37***	1.00				
GER	0.19***	0.20***	0.18***	0.21***	0.43***	1.00			
CAN	0.16***	0.33***	0.13***	−0.02**	0.05***	0.13***	1.00		
AUS	0.21***	−0.06***	0.26***	−0.11***	0.00	0.19***	−0.03*	1.00	
CHN	−0.17***	−0.04*	−0.03	0.03*	0.13***	−0.05***	0.07***	0.03*	1.00

Significance level: 1%***, 5%**, 10%*

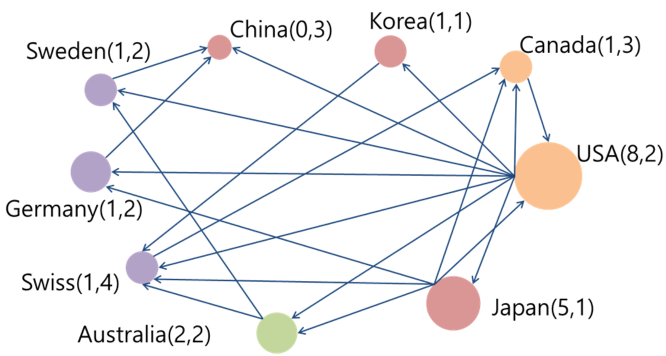


FIGURE 3. Visualization of Granger causality results

4.3. **Identifying the interactions between countries.** In this section, we will look at which countries are leading the interest in the IoT and examine the scale of them. First, we evaluate the vector autoregressive model and examine the Granger causality test to see which countries are leading the interest in the IoT.

Figure 3 visualizes the result at the significance level of less than 5%. The direction of arrow indicates the direction of influence between countries, which is usually expressed as Granger-causes. The number of outgoing and incoming arrows is shown in the parenthesis next to that country's name. The size of node is proportional to the number of outgoing arrows from that node, which implies how much that country influences the other countries. The picture shows that USA is leading the interest in IoT, USA is affecting all countries, and the next most influential country is Japan. Considering that 13 over total 20 outgoing arrows are from USA and Japan, these two countries seem to lead the global interest. A notable part of the results of the Granger causality test shown in Figure 3 is the relatively less convincing position of China (CHN). Considering China's economic volume and international influence, three incoming arrows with no outgoing arrow look quite doubtful. Since Google search is not easily accessible from China, lack of sufficient search data on Google Trends may be a possible reason for this poor result. In this respect, future studies on China are needed to supplement this research.

The left half of Figure 4 shows the magnitude of each country's responses to the impact of the USA as an impulse-response function. The results show that Canada is the most responsive to the impulse of USA. However, the duration is about one week and shorter than that of Japan, Korea, and Switzerland. Responses from Japan, Korea, and Switzerland are small compared to Canada, but the duration is about the double of Canada. The right half of Figure 4 shows the magnitude of each country's responses to impulse of

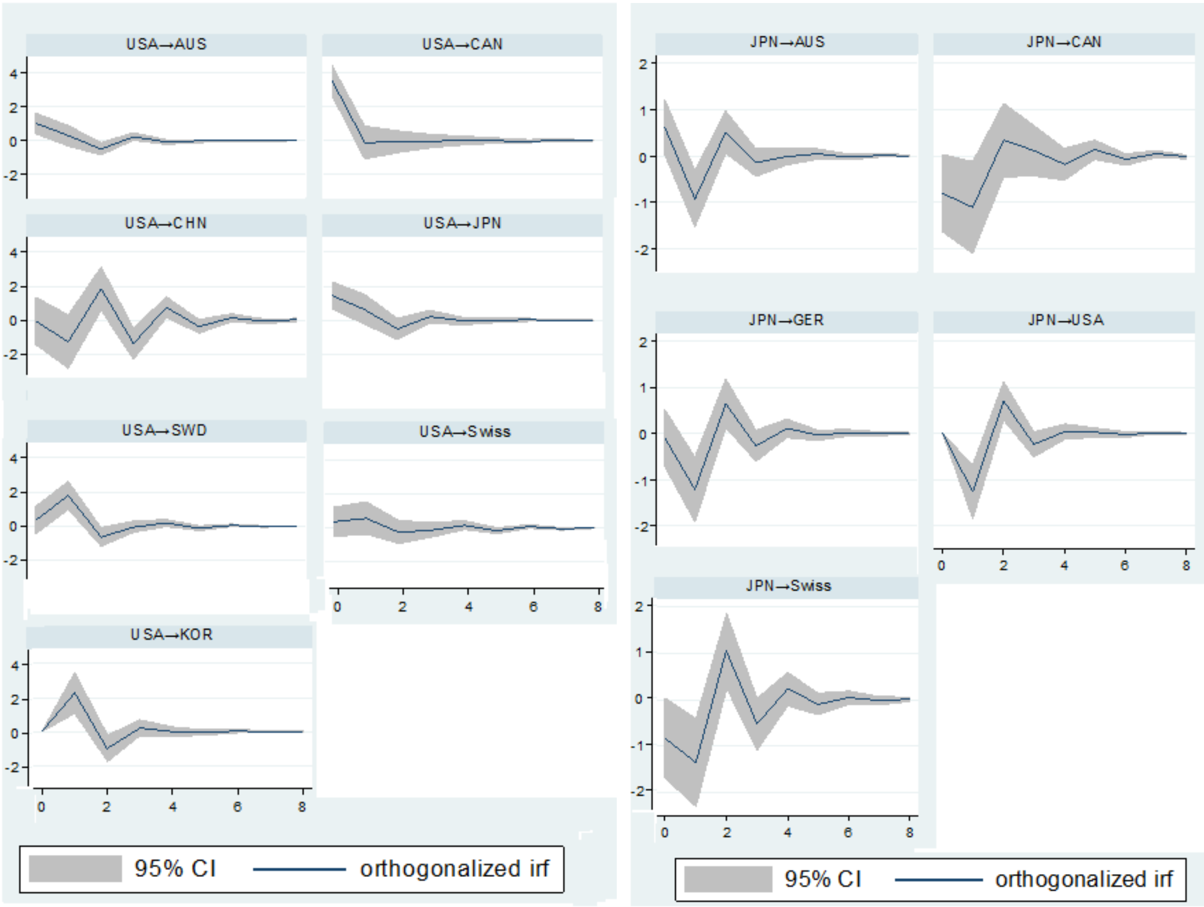


Figure 4. Impulse-response function from USA and Japan to the other countries

Japan. It can be seen that the amount of response is relatively small compared to that of the other countries to USA.

5. **Conclusions and Implications.** In many cases, new technology takes a considerable amount of time for it being introduced and accepted by the public. We can easily find the cases that superior technologies have been failed at the market not overcoming the adoption obstacle. Therefore, for successful adoption of new technology like IoT, it is needed to investigate systematically the general public's interest in the technology and to strategically utilize it. This study has analyzed Google Trends data to track people's interest. Google Trends data can quickly and easily grasp how the public's interest is changing and moving. This study demonstrates new approach to explain each country's evolution on technology adoption and mutual diffusion by analyzing web search data, specifically for IoT. First, authors have examined rankings among countries in terms of search traffic and changing web search volume for IoT to assess each country's adoption capabilities. Second, authors have analyzed the global interest in the IoT through the static correlation and its changing trend through the dynamic correlation to identify similar growth-pattern among countries. Third, authors have identified which countries are leading the interest in IoT through Granger causality test using vector autoregressive model, and the scale by looking at impulse-response function. The results of this study are expected to be useful for future innovation research and policy development using the IoT, and will be helpful for establishing a global innovation strategy at national or enterprise level. By further refining proposed approach, authors anticipate more robust methodology to evaluate technology adoption and diffusion to be devised afterward.

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