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# The National Innovation System (NIS) and Readiness for the 4th Industrial Revolution: South Korea compared with Four European Countries

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## 1. Introduction

Lundvall (1992) defines National Innovation System (NIS) as “elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge.” Specifically, NIS is a concept related to the efficiency of production, diffusion, and use of knowledge. Scholars from the Schumpeterian School, such as Lundvall and Nelson, have advocated the NIS concept. They argued that the differences in NIS among countries have given birth to the differences in innovation performance, and thus, the countries’ economic performance. In this sense, Schumpeterian economics differs from the emphasis on the political institution, as in Acemoglu and Robinson (2012), who suggested that political institutions determine the growth rate of countries, particularly inclusive rather than extractive institutions. In general, political institutions are more binding critically in pre-modern societies or low-income countries than in upper middle- or high-income societies. Using the number of granted US patents and R&D expenditure as a proxy for innovation, Lee and Kim (2009) find that innovation capability is important for economic growth in countries beyond the middle income stage, whereas political institutions are binding for economic growth in lower middle- or low-income countries.

The current study analyzes and compares the national innovation systems of Korea against the four European economies of Italy, the UK, France, and Germany. One focus of the comparative analysis is to determine the extent to which each country is better prepared for the Fourth Industrial Revolution (4IR hereafter). As popularized by Schwab (2016) at the 2016 World Economic Forum, the 4IR refers to the new waves of innovation consisting of several technologies comprising 3D printing, Internet of Things (IoT), artificial intelligence (AI), smart cars, big data, and on-demand economy (sharing economy). In general, the 4IR is regarded as making innovation based on a broad spectrum of technologies from diverse fields and is thus becoming more convergent. The current study attempts to address which aspect of the NIS is friendlier to the 4IR, and which countries boast of a more adequately prepared NIS for the coming 4IR. The next section describes briefly the methodology for analyzing NIS, becuase we need to study the variables that can reveal various aspects of NIS. Section 3 compares the NIS of Korea and four European countries. Finally, Section 4 concludes the paper with a brief remark.

## 2. Five Aspects of the NIS (National Innovation systems) and Readiness for the 4IR

Empirical analysis of innovation and knowledge is challenging because of the difficulty in measuring innovation and knowledge and the lack of data. However, patent data have increasingly become available and used for this purpose because they, especially patent citation data, can be considered as a proxy for the paper trail of knowledge flows. Like academic articles citing each other, patent citations are about which patents cite which other patents, and are presumed to be informative links between patented inventions. In other words, knowledge flows among inventors leave a paper trail in the form of citations in patents (Jaffe et al. 1993). By conducting a survey of inventors, Jaffe et al. (2000) investigate the extent to which citations actually reflect knowledge flows and find that a significant proportion actually do. This condition makes it possible to use the probability of citation as a proxy for the probability of a useful knowledge flow.

A methodology has been developed for quantifying NIS by using patent citation data extracted from the US patents database, and here we will briefly introduce it and explain the usage.[1] In the Korean patent system, only recently has the database included information regarding which patent cited which other patents, but the US Patents and Trademark Office has been collecting citation data for a long time. Citation data of patents represent how existing knowledge is used for subsequent inventions, and thus contains valuable information for the flow of knowledge (acquisition and usage). For this reason, patent citation data is useful for innovation system studies trying to capture efficiency in the creation and usage of knowledge.

Jaffe and Trajtenberg (2002) provide extensive US patent data for researchers conveniently in the form of a CD. Their book also contains a description for the data and methodologies for econometric analysis using patents data. But, their book provides the data for the year of 1999, and their data are updated up to 2006. This paper uses more updated data, updated to mid-2010 or 2015 to provide more recent situation of the NIS of countries. How this paper has contructed the database of up-to-date patents and their citations is explained in the Appendix.

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[1] For further details on the methodology, please refer to Lee (2013) and Lee et al (2 017).

In comparing the NIS of countries, it would be problematic to use patent data from different patent office because they use different standards. Thus it is important to use patent data collected by a particular country to which the largest number of other countries apply for patents. US patents data is a perfect example of such a case, and thus we use patents filed in the US by countries for international comparison. Now let us introduce the main variables describing NIS, which were also used in Lee (2013) and Lee et al (2017), and the detailed technical definitions of these variables are presented in the Appendix.

The first NIS variable is related to the source in the acquisition of knowledge and the degree of localization in the production of knowledge. That is, it regards how much knowledge being created relies on foreign or domestic knowledge bases. In other words, it measures how much knowledge is created domestically by citing the patents owned by inventors of the same nationality. It can be referred to as a measure of the localization of knowledge creation and is a proxy for how often the patent filed by a country cites other patents filed by its citizens. At firm level, it can be self-citation of patents belonging to a firm and is a variable that represents how independently firms produce knowledge. According to Lee (2013), Korea and Taiwan showed a low degree of localization in knowledge creation in the early 1980s, which was similar to that of other middle income countries but much lower than that of advanced countries. However, the degree increased rapidly after the mid-1980s and reached the average level of advanced countries by the late 1990s, indicating a significant catch-up in this regard.

The second NIS variable regards the concentration of actors or patent holders in knowledge creation. It regards whether the producers of knowledge are led by a few big businesses or evenly distributed among a variety of inventors. Clearly, this variable shows a quite even distribution of knowledge producers for advanced countries while knowledge creation is concentrated with a few inventors in the case of typical developing countries.

The third variable for NIS is originality (or knowledge combination). Existing literature describes it as how wide the range of the source of knowledge is when a patent cites preceding patents. That is, we say that knowledge has a high degree of originality if it relies on knowledge from a variety of fields. We may reason that the NIS featuring a higher degree of originality can be considered as better or more ready for the 4IR to the extent that the 4IR require more convergence technologies which are more broadly based and tend to be fusion technologies. Similar to the concentration variable, advanced countries show a relatively higher degree of originality than developing countries. Interestingly, countries from Latin

America show higher degrees of originality compared to South Korea and Taiwan (Lee 2013).

The forth variable for NIS is technological diversification. This measure is about whether countries or firms produce patents in a wide variety of fields or in a few limited areas. A country with more diversified NIS can be regarded as better ready for the 4IR because a broad portfolio in its technological resource may mean a higher possibility of innovation in the era of the 4IR which also means broadening of the scope of innovation activities. Lee (2013) shows that advanced countries have a higher degree of technological diversification than developing countries. In the case of South Korea and Taiwan, the degree of technological diversification has increased since the mid-1980s. Although it was still lower than that of German or Japan, the degree of technological diversification for South Korea and Taiwan has reached the average of high income countries.

The fifth variable for NIS is related to whether or not countries specialize in sectors with fast obsolescence of knowledge or slow obsolescence of knowledge. This notion is expressed as the cycle time of technologies. It represents the length of the life expectancy of the particular knowledge being used. A short cycle time of technology means that the life span of the knowledge lasts only a few years and after that the usage declines dramatically as it soon becomes outdated or less used. Cycle time of technology is calculated by measuring average time lags between the application (grant) years of the citing and cited patents. That is, it means how much on average a patent relies on old technologies for invention of new knowledge. Lee (2013) shows that major advanced countries are specialized in sectors with relatively longer cycle times of technology, while South Korea and Taiwan have shown a tendency to focus on sectors with relatively shorter cycle times of technology since the mid-1980s, as their patents tend to cite other relatively recent patents.

## 3. The NIS during the catch-up stages in Korea

Lee (2013) investigated the major characteristics of the catch-up stage NIS by comparing the NIS of South Korea and Taiwan with the NIS of both other developing and developed countries. He uses the above five variables to empirically test the determinants of per capita GDP growth. One of the most important finding of Lee (2013) is that successful catching-up countries and firms have specialized in sectors with short cycle times of technology.

The reasons that specializing in sectors with short cycle times is more advantageous for catching-up growth are explained in the following. First, specializing in fields with short cycle times of technology means that existing knowledge becomes obsolete fast. This would mean lower entry barriers for latecomers because they can afford to rely less on the existing knowledge dominated by advanced countries. Second, having short cycle times of technology, as in information technologies, means that new technology arrives more frequently, resulting in high growth potential. Additionally, specializing in sectors with short cycle times of technology would facilitate quickly raising the degree of knowledge localization (measured by self-citation at the country level). That is, it would be advantageous in achieving fast and successful localization of knowledge creation because reliance on old or existing knowledge controlled by advanced countries would be relatively low.

In country level empirical studies, Lee (Chapter 3, 2013) demonstrates that there is a significant correlation between having more patent applications in fields related to shorter cycle times of technology and higher per capita GDP growth rate, such as in East Asian countries including South Korea and Taiwan. In contrast, economic growth in high income countries as well as in other middle income countries, is positively related to specialization in technologies with long cycle times, although they differed in that advanced economies specialized in high value-added sectors (e.g. pharmaceuticals), and other middle income countries, in low value-added sectors (e.g. apparels), within the long cycle technologies. This finding suggests that specializing in sectors with short cycle times of technology is a way to avoid direct competition with advanced countries, and provide a niche market for latecomer countries with a certain profit rate.

Lee’s study considered other variables representing innovation systems of various dimensions. These include the cycle time of technologies, originality, localization of knowledge creation, innovator concentration, and technological diversification. He finds that the degree of knowledge localization and technological diversification in economies that have successfully caught up has rapidly increased over time. At the same time, such countries have specialized increasingly in short-cycle technologies. Thus, these three variables seem to hold the key to the question of the mechanism of economic catch-up. As discussed above, they also appear to occur together and to complement each other. Statistically, there is very high degree (as high as 0.7) of correlation between knowledge localization and technological diversification. In contrast, the variable of cycle time does not show such a high correlation with either of the two variables. Also, while advanced countries all tend to show high degrees of knowledge localization and technological diversification, they all seem to have more patents in long cycle technologies, which is exactly the opposite of the case with successful catching-up economies. Although the variable of knowledge localization shows rapid increases over time in catching-up economies, the variable is significant in the performance equation only in advanced economies and their firms, whereas it was too low to be significant in middle income countries. The nature of technological diversification appears similar to that of knowledge localization. Based on this information, we take both diversification and localization as the end-state variables and the cycle time as an effective transition variable that guides us to end-state.[2]

Before the mid-80s, South Korea and Taiwan specialized in sectors with low-end, long cycle times of technology such as textiles or clothing. Since the mid-1980s, however, they have started to enter industries with short cycle times of technology such as electronics, semi-conductors, signal equipment and digital TVs. As a result, they accomplished technological diversification by entering a variety of industries, and at the same time, the degree of localization of knowledge creation continued to rise. To sum up, consecutive entry into sectors with short cycle times of technology resulted in technological diversification, and specializing in sectors with short cycle times of technology also made firms rely less on the technology of advanced countries, enabling them to achieve fast and successful localization of knowledge creation.

So far, we have been discussing catching-up NIS. Successful catching-up countries such as South Korea and Taiwan accomplished the desired level of catching up by specializing in sectors associated with short cycle times of technology. In contrast, the degree of concentration and originality for those countries is not very different from other developing countries. Thus, Lee argued that the degree of concentration and originality is not the main element for catching-up growth. However, it is also established that the top-tier high income countries all tend to have a more even distribution of inventors or less concentration, as well as high originality in their patent portfolios. This fact could mean that South Korea may also need to improve on these aspects or to switch to the NIS more typical for top-tier advanced countries. This issue is explored in more detail in the following section.

## 4. The NIS in the 2010s in Korea and Four European Countries.

[2] Lee (2013: p .213–214)

Results of characterizing the NIS of Korea and four European countries are shown in Figures 1 to 5. We discuss each country's NIS using the figures.

First, the NIS of Italy has the longest cycle time as compared to the other countries. This finding implies a sound basis for high profit capability. However, the NIS of Italy also reveals a low degree of technological diversification and knowledge localization, as well as a medium level of originality. The longest cycle time of the Italian NIS apparently demonstrates consistency with the SME-oriented nature of Italian industry with strength in tacit knowledge-oriented sectors, such as machine tools. Although this feature suggests something positive, the NIS of Italy quality tends to indicate a low degree of preparedness for the 4IR as indicated by low originality and less diversification.

In comparison, the NIS of the UK reveals the highest degree of originality and relatively long cycle time of technologies compared with other European countries. However, the NIS of the UK is not significantly diversified and also has the lowest degree of intra-national diffusion or knowledge localization. The last feature of low degree of knowledge localization is not necessarily negative because it may indicate a high degree of internationalization, implying heavy reliance on international sources. In terms of preparedness for the 4IR, the UK stands well in terms of originality but not that well in terms of technological diversification.

The NIS of Germany has the highest degree of diversification and knowledge localization. Germany also has relatively high originality and medium cycle time of technologies. Thus, Germany can also be regarded as well-prepared for the 4IR based on its highest degree of technological diversification and relatively high level of originality.

By contrast, the values for the five variables of the NIS in France all tend to be in the middle as compared with other countries. In other words, France has no clear-cut distinction in any of the five aspects of the NIS.

Finally, Korea manifests the highest degree of knowledge localization and concentration, which is regarded as a feature of the east Asian model of NIS in the sense of somewhat nationalistic and big business-led NIS. A very high degree of knowledge localization is also observed in Japan. Korea must also catch up with the European countries in terms of obtaining additional patents in long cycle time-based technologies and further technological diversification. Although the short cycle technologies and big business-based NIS has served well as the catch-up mode of NIS, the former does not bode well in terms of long-term perspective and preparedness for the 4IR which require more diversity. The NIS of Korea is still low in terms of originality.

[ Figures, 1 to 5]

Lee (2013) confirms that South Korea passed through the first technological turning point after the mid-80s by specializing in and entering sectors with short cycle times of technology. Thus, the country has been very successful in catching up with the income level of advanced countries. Since the 2000s, the South Korean government has promoted industries, such as biotechnology. Consequently, South Korea successfully passed through the second technological turning point by entering sectors with long cycle times of technology. This process is still continuing. Although such industrial promotion policy has succeeded in producing a certain number of patents (knowledge), a general agreement prevails that those industries have still not achieved a significant commercial success (Lee et al 2017). Leaping into sectors with long cycle times of technology is not the only problem South Korea faces. As the analysis in this paper reveals, the country must also lower the excessive degree of concentration by big businesses. However, making this transition with the current NIS led by big businesses will be very difficult. Instead, the participation of various agents is necessary, such as the small and medium enterprises.

## 5. Summary and Concluding Remarks

The current study analyzes and compares the national innovation systems of Korea in comparison with four European economies of Italy, the UK, France, and Germany. For these five economies, the five aspects of the NIS in the 2010s are analyzed using the US patent data, such as originality, cycle time of technologies, knowledge localization, technological diversification, and inventor-level concentration of innovation activities.

The NIS of UK and Germany exhibit a high degree of originality and technological diversification, which is good in terms of preparedness for the 4IR. Meanwhile, although the NIS of Italy boasts of the longest cycle time, such feature implies a low degree of preparedness for the 4IR as indicated by low originality and less diversification. In the meantime, the NIS in France tends to be in the middle in the five aspects of the NIS, thereby exhibiting no clear-cut distinction in any of the five aspects.

In comparison, Korea shows the highest degree of knowledge localization and concentration, which is regarded as a feature of the east Asian model of NIS in the sense of somewhat nationalistic and big business-led NIS. Although the short cycle technologies and big business-based NIS have served well as the catch-up mode of NIS, the former does not bode well in terms of long-term perspective and preparedness for the 4IR. Its NIS is still low in terms of originality.

**Appendix on Data Sources and Figures.**

1) Data Sources

The data used in this study were collected from the United States Patent and Trademark Office (USPTO) Grant Red Book (http://patents.reedtech.com/pgrbft.php). Patent Grant Full Text contains the full text, including tables, sequence data, and "in-line" mathematical expressions of each patent grant issued weekly from January 1976 to the present. The file format is SGML (Standard Generalized Markup Language) or ASCII text. These text data include patent number, series code and application number, type of patent, filing date, title, issue date, inventor information, assignee name at time of issue, foreign priority information, related US patent documents, classification information, US and foreign references, attorney, agent or firm/legal representative, Patent Cooperation Treaty (PCT) information, abstract, specification, and claims. Approximately 4,000 patent grants are issued per week. From these text data, we construct a new DB through the data extraction process using SAS text mining. We have then analyzed these data to construct the values for the five measures of the NIS discussed in Section 2.

2) Definitions of the Five NIS variables

Using granted patents DB and citation DB, we calculated Localization, HHI (Hirschman-Herfindahl index: concentration of assignees), Originality, Technological diversification, and the cycle time of technologies.

- Localization (Jaffe et al., 1993; Lee and Yoon, 2010; Lee, 2013)

$$Localization_{xt} = \frac{n_{xxt}}{n_{xt}} - \frac{n_{cxt}}{n_{ct}}$$

$n_{xxt}$: the number of citations made to country x's patents by country x's granted in year t

$n_{xt}$: the number of all citations made by country x's patents granted in year t

$n_{cxt}$: the number of citations made to country x's patents by all patents, except country x's patents filed in year t

$n_{ct}$: the number of all citations made by all patents filed in year t, except country x's patents

- Hirschman-Herfindahl index: concentration of assignees)(Lee, 2013)

$$HHI_{xt} = \sum_{i \in I_x} \left(\frac{N_{it}}{N^*_{xt}}\right)^2,$$

where $I_x$ is the set of assignees, $N_{it}$ is the number of patents filed by assignee $i$ in year t, and $N^*_{xt}$ is the total number of patents filed by country x in year t, excluding unassigned patents.

- Originality (Hall et al., 2001; Trajtenberg et al., 1997)

$$Originality_i = 1 - \sum_{k=1}^{N_i} \left(\frac{NCITED_{ik}}{NCITED_i}\right)^2,$$

where $k$ is the technological sector (specially patent class $k$), $NCITED_{ik}$ is the number of citations made by the patent $i$ to patents belonging to patent class $k$, and $NCITED_i$ is the total number of citations made by patent $i$.

- Technological diversification (Lee, 2013)

This number pertains to the quantity of technological sectors in which a country has registered patents out of a 438 three-digit sector in the U.S. patent classification system.

$$Diversification_i = \frac{N_i}{total\ number\ of\ sectors},$$

where $N_i$ is the number of technological sectors of patent $i$. The total number of sectors is 438 until 2016.

- Cycle time of technologies = backward Lag (Jaffe et al., 1993)

For any publication Patent A, Publications 1, 2, 3 cited in A are backward citations of A

$$Cycle\ time\ of\ technologies = application\,(grant)\ \ year\ of\ \cancel{p}\underline{P}atent\ A - application\,(grant)\ year\ of\ citations\ of\ \cancel{p}\underline{P}atent\ A$$

In this case, the windows of opportunity are 25 years.

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Figure 1 Average cycle time of technologies

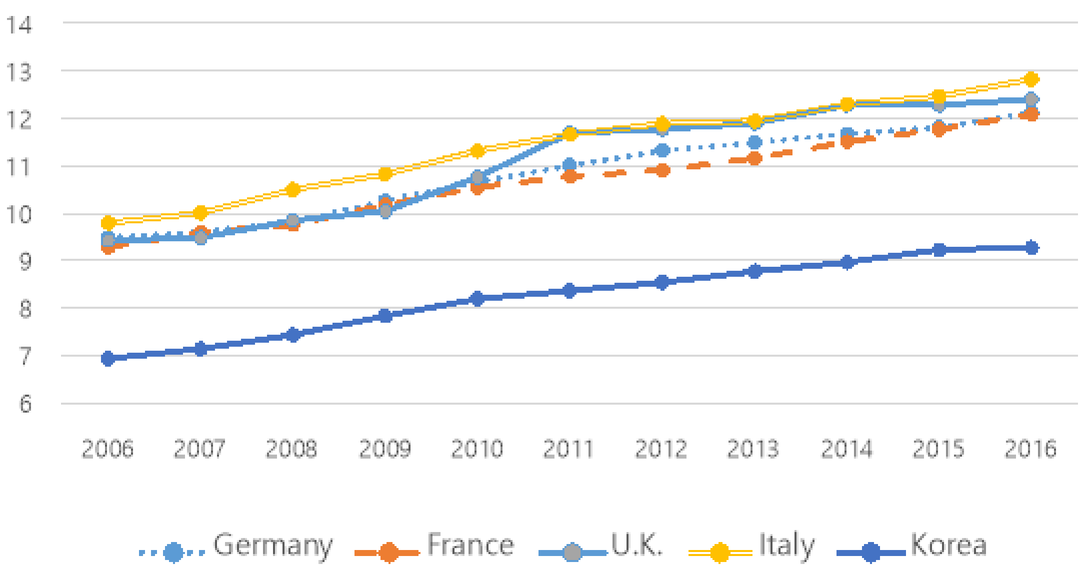



Figure 2 Intra-national diffusion of knowledge = localization

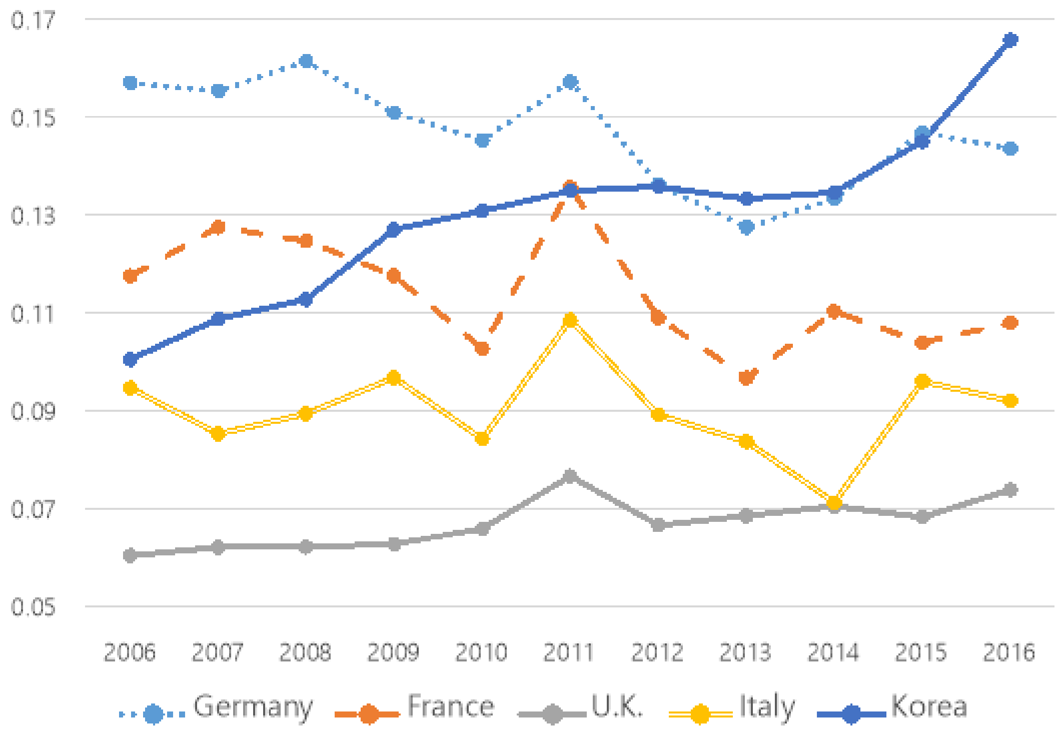


Figure 3 Index (HHI) of assignee concentration

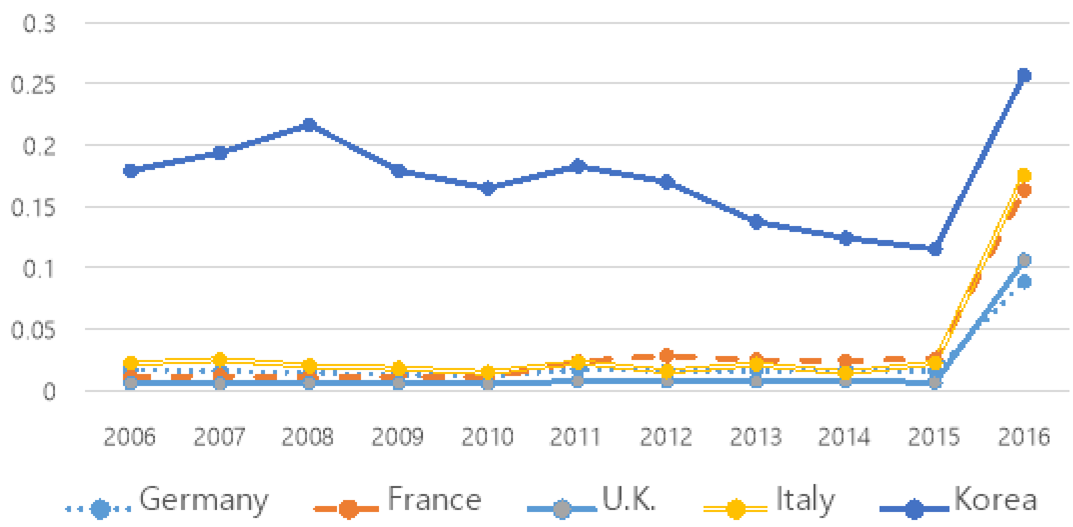
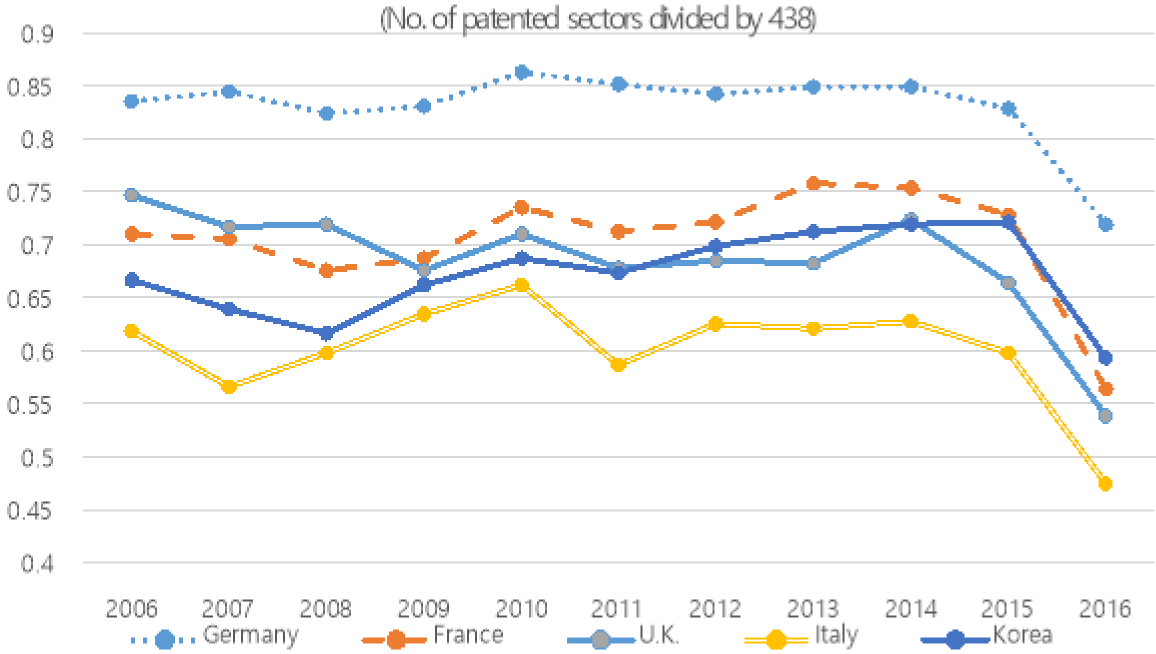



Figure 4 Technological diversification:
(No. of patented sectors divided by 438)



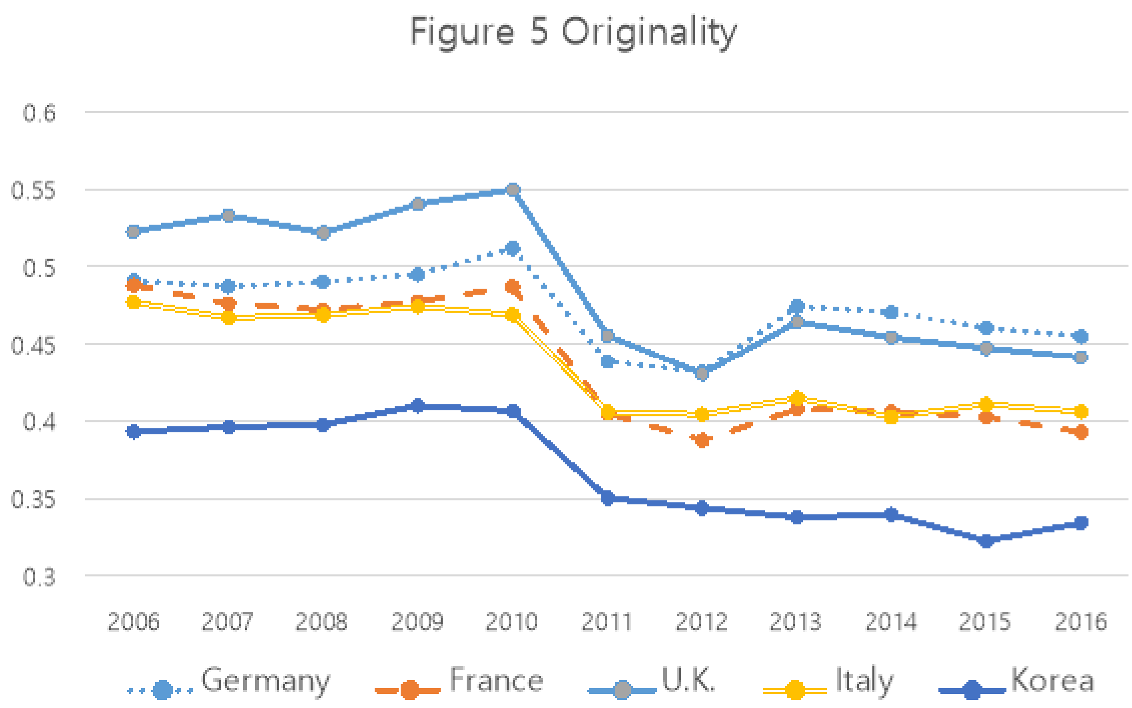


Figure 5 Originality
0.6
0.55
0.5
0.45
0.4
0.35
0.3
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Germany
France
U.K.
Italy
Korea