Specialization and Integration of Emerging Technology

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Abstract--**There is a growing consensus that the emerging technology will have a substantially profound economic impact on the manufacturing sector. The purpose of this study is to present the specialization and integration state of emerging technology of institutions and countries by employing patent bibliometric analysis and statistic method based on the EPO database. There are two main findings from our empirical results: From the view of institution, some companies put emphasis on technology specialization, while other institutions are involved in various sub-fields. From the perspective of country, specialization and integration state of countries is rather different among four emerging technology fields. China appears to highlight the persistence in big data technology, but exhibits low level of persistence and depth in other emerging technology fields. Furthermore, our findings have important implications for countries and institutions to make policies and strategies.**

I. INTRODUCTION

There is a growing consensus that the emerging technology will enormously improve the productivity, create more employment opportunities and significantly stimulate economic growth. And it is going to change dramatically the way human being live and the product human being use. Till now many companies or public research institutions have huge expenditure in the R&D investment of emerging technology. Emerging technology has the following characteristics: (1) emergence or developing (2) emerging technology could significantly and rapidly develop new ideas or new technologies and will have a substantial impact on economic structure. 3D Printing Technology, Big Data Technology, Integrated Circuit Technology and Carbon Nanotubes and Graphene Technology, are characterized by rapid development in terms of significance and developing rate of new ideas and technologies. There is more and more evidence indicating emerging technology could create enormous contribution for the global world. This study investigates technological specialization and integration pattern of four main emerging technology fields in the worldwide.

Specialization and integration are two sides of the technology development. On one side, specialization is the key process through which new bodies of economically relevant knowledge are developed [16]. On the other hand, specialized competence need to be integrated, or coordinated, in order to produce new and better products. The specialization processes have caught up quite a lot of attention on the side of index and approach to measure and compare them at various levels of analysis, and at the same time the indicators capable of capturing their key characteristics of those processes which aim at coordinating and integrating specialized technology have been more and more widely used.

The joint analysis of technology specialization and integration process is relevant for both theory and practice. It is a big challenge for an institution to draw on more extensive networks of technology and effectively coordinate these dispersed sources. Also at country level, the ability to increasingly coordinate dispersal technology processes appears to be a key competitive variable for national innovation systems [5]. However, the analysis of specialization and integration state among emerging technology fields has not yet been studied until now. This article is to fill this gap.

To be specific, this paper aims to answer the following two questions.

(1) What is the current state of emerging technology specialization and integration for institutions?
(2) What is the level of emerging technology specialization and integration for countries?

Therefore, our study demonstrates the current state of technology specialization and integration for institutions and countries. And the key characteristics can be measured relying on the innovative use of patents and citations data. The remainder of this paper is structured as follows: Section 2 introduces the data preparing and patent analysis methods. Section 3 analyzes the current state of technology specialization and integration for institutions and countries, including technology breadth, evolution of breadth and technology depth. Section 4 concludes the findings and suggestions for making technology strategies and policies.

II. DATA AND METHODOLOGY

A. Data

Complex emerging technical information can be organized into logical and understandable statistics when examining the status of specialization and integration characteristics in a specific technology area. Therefore, the analytical method based on patent data can be used as a useful tool. The European Patent Office (EPO) is a federal agency for granting patents to patentee. Both domestic and foreign applicants may submit patent applications to the EPO and thereby request protection of their intellectual property. The granted patent proportion of members and non-members is almost the same. Thus, patents related to emerging technologies in the EPO are more representative, comprehensive and international. Over decades, many laboratories have carried out a series of research based on EPO-granted patents that are considered to have higher technological value than foreign patents and thus can indicate the high quality of invention.

In this study, patent data was retrieved from the EPO database. A keyword query approach is used to identify the emerging technology patent data from the EPO databases. The keywords are based on the definition of emerging technology and were previously used in studies. Therefore, the retrieved strategy in accordance with the emerging technology was compiled and the patent data for this study was downloaded from the Internet on December 31, 2013. The patent number of 3D Printing Technology, Big Data Technology, Integrated Circuit Technology and CNTs and Graphene Technology is respectively 5276, 4606, 11622 and 8907 pieces. According to the literature and Chinese expert's suggestions, table 1 shows the technology classification system and codes of four emerging technology fields. However, institutions' names changed along with time, for example, "Hewlett-Packard Development Company L.P." may be used in early time while Hewlett-Packard Development Co is frequently used in recent time. In order to compare the level of technology specialization and integration among different institutions, we resolved institutions' name variations using fuzzy matching by the VantagePoint software.

TABLE 1 CODES IN SUB-FIELDS RELATED TO FOUR EMERGING TECHNOLOGIES

	Technology	Sub-fields	Code
CNTs and Graphene Technology	CNTs Structure	CNTs Characterization Technology	CNC
	CNTs Preparation Technology	CNTs Preparation Technology	CNP
		CNTs Purification Technology	CNU
		CNTs Modification Technology	CNM
	CNTs Performance and Application	CNTs Performance and Application	CAN
	Graphene Structure	Graphene Characterization Technology	GRC
	Graphene Preparation Technology	Graphene Preparation Technology	GRP
		Graphene Purification Technology	GRU
		Graphene Modification Technology	GRM
	Graphene Performance and Application	Graphene Performance and Application	GRA
Integrated Circuit Technology	**Technology**	**Sub-fields**	**Code**
	Cleaning Technology	Cleaning Technology	CLT
	Lithography Technology	Lithography Technology	LIT
	Etching Technology	Etching Technology	ETT
	Thin Film Technology	Thin Film Deposition Technology	TFD
		Thin Film Epitaxy Technology	TFE
	Doping Technology	Doping Technology	DOT
	Annealing Technology	Annealing Technology	ANT
	Planarization Technology	Planarization Technology	PLT
	Packaging Technology	Interconnect Technology	INT
		Packaging Technology	PAT
3D printing Technology	**Technology**	**Sub-fields**	**Code**
	Curing Technology	Curing Technology	CUT
	Sintering and Bonding Technology	Laser Sintering Technology	LST
		Spray Bonding Technology	SBT
	Material Melt Bonding Technology	Wire Melt Bonding Technology	WBT
		Filum Melt Bonding Technology	FBT
		Powder/Granular Materials Melt Bonding Technology	PBT
	Plate Laminated Technology	Plate Laminated Technology	PAT
	3D Bioprinting	3D Bioprinting	3DB
	3D Food Printing	3D Food Printing	3DF
Big Data Technology	**Technology**	**Sub-fields**	**Code**
	Big Data Acquisition and Preprocessing	Big Data Acquisition	BDA
		Big Data Preprocessing	BDP
	Big Data Storage and Management CNTs Performance and Application	Distributed File System and Database	DFS
		Access Interface and Query Language	ATQ
	Big Data Computing Mode and System	Big Data Computing Mode and System	BCM
	Big Data Analyzing and Mining	Big Data Analyzing and Mining	BDM
	Big Data Visualization	Big Data Visualization	BDV
	Big Data Security and Privacy	Big Data Security and Privacy	BDS
	Big Data Application	Big Data Application	BDC

B. Patent analysis method

The technology accumulation pattern has been stressed recent years. A number of precise cases which reveal how the accumulation of results over time have been provided. For instance, Conant [8] described the process of accumulation of quantitative results in physics that led to Lavoisier's revolution in modern chemistry. If a country is specialized in the low opportunity technical or scientific fields, the country may not get effective development. Trade and growth indicators will reflect such 'bad' specialization. On this basis a number of bibliometric indicators have been developed over years to study the patterns of scientific specialization at various levels of analysis. Similar results and indicators have also been derived when analyzing the patterns of technological specialization of large, innovating organizations [9]. The concept of technology specialization in terms of the technology breadth and its evolution, its persistence and stability, over time has been developed [4]. Meliciani [17] have therefore devoted much effort to matching technological specialization indicators and countries' growth indicators. Lall [15] argued that the technological specialization and leading exporters of developing countries differ greatly, as do the strategies used to achieve competitiveness. Chiappini [7] examined the evolution of the patterns of technology specialization of 11 Euro area countries in the period 1990-2008.

The persistence and cumulativeness of technology specialization patterns are not the only dimensions relevant to a study of the institutions or countries. Indeed, the coordination and integration of different types of competence play a crucial role in the process of innovation. Integration issues have been studied at length in organizational sciences, natural science, strategy and innovation management literature, beginning with the seminal work by Lawrence and Lorsch [14]. For example, Granstrand et al. [9] studied the distributed capabilities to monitor and integrate technologies for companies. Kapoor R [12] draw on detailed firm-level data from the semiconductor industry to analyze how integrated incumbents, beyond shifting to the specialized mode, reconfigured in the face of industry's vertical disintegration so as to coexist with the specialized firms. Zhu [23] found that acquiring firms in service information technology industries where post-acquisition autonomy is more important in value creation outperform those in manufacturing industries where post-acquisition integration is preferred. Balda [3] presents the integration of WTE technologies into the electrical system for the low-carbon growth. Some developing measures of integrating process were identified. On the side of integration measuring indicator, Nesta [18] measured the integration of the knowledge base of firms in terms of their technological coherence. Coherence is a measure of the relatedness of firms' technological capabilities. A number of indicators have been developed based upon various definitions of 'distance' to analyze coherence. The second dimension of integrating activities is related to the complexity and criticality that characteristics specific fields. Then the depth index has been used. In order to manage such complex interactions it is necessary to maintain capabilities which span all the sub-problems, tasks, and activities concerned. Prencipe [19] studied depth in the case of the evolution of the aero-engine control system. His study showed the importance of considering this additional dimension (depth) alongside breadth. Henderson analyzed the role played by capabilities of integrating in pharmaceuticals R&D. Brusoni and Geuna [5] attempted to quantify integration in term of the depth of firms' knowledge bases using publicly available patent data. The technology integration of a country has been determined in terms of the depth of its technology as measured by the specialization across emerging technology fields. Hence, specialization and integration patterns of institutions or countries could be measured through indicators of persistence and depth. In this study, the index of persistence indicates the 'technology distance' (variation in breadth) of a given technology in different periods. Depth looks at the involvement in different sub-fields of one emerging technology. Three indicators are explained as follows,

C. RAI

This indicator is used to measure technology specialization. The breadth of certain technology in an institution can be calculated in absolute levels (how many citations in each sub-field) or in terms of its relative specialization in certain sub-field. Both approaches provide some information on the breadth of the technology of an institution in terms of the presence in certain technology fields and the institutions relative specialization in other sub-fields. In our study, the technology breadth of one institution is defined by calculating how many citations in each technological sub-fields or in the term of its relative specialization in certain technological sub-fields. Some information could be provided in aspect of one technology field's present situation and the institutions relative specialization in sub-fields through two approaches defined by Brusoni [5]. The index RAI (Relative Advantage Index), derived from the Revealed Technological Advantage index [20], is obtained standardizing the activity index (AI). The RAI index is defined as the share of citations in a given sub-field in the citation portfolio of a given institution relative to the share of citations in a given sub-field for all the institutions in the overall of citations. The RAI index illustrates whether an institution has relative advantage (RAI>0) in a sub-field or disadvantage (RAI<0).

$$\mathrm{AI} = \left(\frac{P_{ij}}{\sum_i P_{ij}}\right) / \left(\frac{\sum_j P_{ij}}{\sum_i \sum_j P_{ij}}\right) \qquad RAI = \frac{AI-1}{AI+1} \tag{1}$$

Where P= number of cited times, i=1…10= number of sub-fields and j=number of institutions.

The excellent specialization sub-fields could be defined as which the institution has a RAI>0.3.

D. Similarity

This indicator is used to measure technology persistence. To examine the changes in the breadth of emerging technology of one institution in terms of number of sub-fields, a measure [10] of similarity is used. The following similarity index (S_k) provides a measure of the technology distance between the breadth of the specialization profile of one institution in the two periods. The distance (variation in breadth) in technology specialization across time can be calculated by a non-central correlation coefficient of the vectors (f_i and f_j) of citation share in each sub-field for one institution in the two periods.

$$S_k = \frac{f_i f_j'}{\sqrt{(f_i f_i')(f_j f_j')}} \quad (2)$$

Where K=1-40 institutions (10 institutions in each technology field) and i=period 1995-2000 and j=period 2008-2013. The similarity measure is bounded between 0 and 1, and the greater the degree of similarity between the breadth of the institutions during the two periods, the closer it is to unity.

E. Depth

This indicator is used to measure technology integration. In order to analyze how integrated institutions are across the sub-fields, the indicator of depth based on the index RAI is calculated. Depth is measured by the ratio between ∑x and y (defined below). The numerator of the indicator shows how many sub-fields are relatively specialized (RAI>0), and the denominator is the number of the sub-fields. Thus the depth is derived using the formula below and it varies between 0 and 1. It is 0 when the institution considered does not exhibit specialization in any sub-fields in each emerging technology field. It is 1 when the institution considered is fully integrated across all sub-fields. In this study, the institution's Depth>0.5 can be defined as an integrated institution.

$$x = \begin{cases} 1 & if\ RAI_i > 0 \\ 0 & otherwise \end{cases}$$

y= the number of sub-fields

$$DEPTH_j = \frac{\sum_i x_i}{y} \quad (3)$$

Where i=1…10 number of sub-fields j=1…10 number of institutions

III. RESULTS

Technological specialization and integration pattern has been measured in this section on the level of institution and country respectively. Emerging technology is appeared as the future trend and may be the important factor of one developing country (region) to realize its economic catch-up strategy. Four fast growing and rapidly changing technology fields (3D Printing Technology, Big Data Technology, Integrated Circuit Technology and Carbon Nanotubes and Graphene Technology) have greatly increased its contribution to economic growth and the way human being live. So they are chosen as the research objects in this study. The brief introduction of four emerging technology fields is as follows. Carbon Nanotubes and Graphene Technology (CNTs and Graphene): Various carbon nanomaterials including fullerene, single/multiwall carbon nanotubes (CNTs), and graphene have attracted considerable attention in recent years because of their extraordinary mechanical, electrical, and thermal properties [1]. Among them, CNTs and graphene are the representative ones with one and two-dimensional nanostructure for prospective applications in solar cells, supercapacitors, batteries, and polymer nanocomposites [2]. Integrated Circuit Technology: it is the development of a new wire bonding technology copper ball on gold bump bonding in current wire bonders with both 1mil copper and gold wires. It covers material and tool selection, wire bonding process window development, electrical characterization and reliability studies. The material and tool selection of Integrated Circuit Technology include cooper wire, experimental chip, capillary and wire bonder. Process window development focuses on two crucial stages, copper free air ball formation and bonding process window development for both gold bump and cooper ball bonded on Au bump [11]. 3D Printing Technology: According to ASTM (American Society for Testing and Materials), it is a process of making three dimensional solid objects from a digital model and is achieved using additive processes, where an object is created by laying down successive layers of material [13]. 3D Printing Technology is currently assessed at more than $3 billion with an expected rise to $13 billion by 2018 and $21 billion by 2020 [22]. Big Data Technology: it is a collection of data sets, which are enormously large and complex that conventional database systems cannot process within desired time. Although conventional SQL-based databases have proved to be highly efficient, reliable, and consistent in terms of storing and processing structured (or relational) data, they fall short of processing Big Data, which is characterized by large volume, variety, velocity, openness, inappropriate structure, and visualization among others [6]. The processing and analysis of Big Data now play a central role in decision making, forecasting, business analysis, product development, customer experience, and loyalty [21].

A. The institution level analysis

1. The breadth of emerging technology

TABLE 2 TOP 3 FIELDS AND CORE FIELDS IN FOUR EMERGING TECHNOLOGY FIELDS

Fields	Institutions	Top3 sub-fields	No. fields	Core specialization RAI>0.3
CNTs and Graphene Technology	UNIV NORTH CAROLINA	CNU GRU	2	GRU
	UNIV LELAND STANFORD JUNIOR	CNC CAN	2	CNC
	CALIFORNIA INST OF TECHN	CAN	1	
	TOSHIBA KK	CAN GPA	2	GPA
Integrated Circuit Technology	IBM	ETT LIT TFE	3	LIT TFE
	MICRON TECHNOLOGY INC	ANT DOT INT	4	CLT TFE
	MOTOROLA INC	ANT PAT PLT	4	PLT
	TEXAS INSTRUMENTS INC	PAT TFE DOT	5	PAT TFE
3D Printing Technology	NANOGEN INC	3DB	1	3DB
	3D SYSTEMS INC	CUT PAT PBT	3	CUT PAT
	CHILDRENS MEDICAL CENTER	LST PBT WBT	5	LST PBT WBT
	3M INNOVATIVE PROPERTIES CO	CUT FBT LST	4	CUT FBT
Big Data Technology	IBM	BDM BDS DFS	3	BDM
	TM SF MEDIA HOLDINGS L C	BDC BDV	2	BDC
	EMC CORP	BDC BDS BDA	4	BDC BDS
	SIEBEL SYSTEMS INC	ATQ BDV	2	ATQ

Note: No. fields: number of sub-fields with RAI>0.

The four emerging technology fields show rather different both in terms of technology concentration and specialization. In the field of CNTs and Graphene Technology, the top 4 cited times institutions focus on certain sub-fields and have relatively important citation portfolios. For example, UNIV Leland Stanford Junior (US) and Toshiba KK (JP) have a distinctive specialization in CNTs Characterization Technology Graphene Performance and Application and these being among the top 3 fields with the index RAI of respectively 0.73 and 0.81. In the field of Integrated Circuit Technology, the top 4 cited times institutions are less concentrated. For instance, the four sub-fields (RAI>0) in MOTOROLA INC (US) are Annealing Technology, Doping Technology, Interconnect Technology and Thin Film Deposition Technology with no fields RAI>0.3. This specialization profile seems to point to a specific market focus for MOTOROLA INC. The pattern of 3D printing technology is similar to CNTs and Graphene Technology. For example, the 3D SYSTEMS INC (US) has a clear specialization profile with an important distinctive specialization in Curing Technology (RAI=0.51) and Plate Laminated Technology (RAI=0.41). And for the field of big data technology, the top 4 cited institutions show a more diversified pattern of specialization making it quite difficult to have characteristic in terms of specific competences.

From the result of this preliminary analysis, it is clear that the institutions of the four emerging technology fields rely on different development pattern (the institutions of CNTs and Graphene Technology and 3D Printing Technology exhibit rather distinctive specialization while the institutions of the other two technology fields show broad specialization profiles). However, analyzing the cited times during the whole period provides only limited information on the breadth of knowledge of different institutions in different emerging technology fields. In order to fill this gap, we focus on the evolution of the breadth of the technology development over time.

2. The evolution of breadth

To study persistence of the four emerging technology fields, we examine their citation portfolios in two periods: 1995-2000 and 2008-2013. With the aim of examining trends in the evolution, the breadth of emerging technology is compared in the two periods. It can be examined by looking at which sub-fields are active in both periods (persistence), and which sub-fields certain institutions cited at the end of the period (entry), or which fields some companies cited at the beginning only (exit). Measures of similarity and concentration during the both periods are calculated for each institution citation profile. The changes in the breadth of emerging technology in terms of entry, exit and persistence in the citations to sub-fields are calculated for the top 4 cited times institutions in the four emerging technology fields. Table 3 shows the number of sub-fields in which certain institution was active in the second period but not the first (entry: number of new sub-fields in the second period); the number of sub-fields in which some institutions no longer has citations (exit: number of sub-fields exiting); and finally the number of fields in which the institutions cite in both period (number of persistent fields in the two period).

In terms of similarity, different emerging technology fields show different level of similarity. In the field of Big Data and CNTs and Graphene Technology, the index of the top 4 cited times institutions is nearly at 0.5. The most institutions of the other two emerging technology fields show a high level of similarity.

Overall, the analysis of the technology breadth of the institutions in the four emerging technology fields reveals a high level of heterogeneity at the level of the institutions in the field of active involvement and in the field of specialization when considering either the entire period or the changes from beginning to the end. In the field of Integrated Circuit Technology and 3D Printing Technology field, the institutions have a high level of similarity in their portfolio of citations at the early stage and later stage and some evidence of increasing in their breadth. And the other two emerging

TABLE 3 THE EVOLUTION OF EMERGING TECHNOLOGY BREADTH IN DIFFERENT INSTITUTIONS

	Institutions	No. new sub-fields in 2003-2013	No. exiting sub-fields	No. persistent sub-fields	Similarity measure
CNTs and Graphene Technology	UNIV NORTH CAROLINA	2	1	0	0.498
	UNIV LELAND STANFORD JUNIOR	1	2	1	0.027
	CALIFORNIA INST OF TECHN	0	1	0	0.542
	TOSHIBA KK	1	2	0	0.346
Integrated Circuit Technology	IBM	3	0	4	0.925
	MICRON TECHNOLOGY INC	0	2	8	0.897
	MOTOROLA INC	0	2	4	0.665
	TEXAS INSTRUMENTS INC	3	0	5	0.795
3D Printing Technology	NANOGEN INC	0	1	0	0.759
	3D SYSTEMS INC	5	0	1	0.391
	CHILDRENS MEDICAL CENTER	0	5	0	0.668
	3M INNOVATIVE PROPERTIES CO	0	0	3	0.739
Big Data Technology	IBM	2	1	2	0.592
	TM SF MEDIA HOLDINGS L C	0	2	0	0.455
	EMC CORP	1	2	1	0.580
	SIEBEL SYSTEMS INC	2	0	0	0.587

technology fields indicate low level of breadth. And the analysis allows a few clear patterns at the level of the individual institutions to be highlighted. For instance, UNIV TSINGHUA (CN) is specializing in Graphene Characterization Technology, RENESAS TECH CORP (JP) in Packaging Technology, NUONICS INC (US) in Laser Sintering Technology and SIEBEL SYSTEMS INC (US) in Access Interface and Query Language Technology.

3. The depth of emerging technology

Table 4 presents the depth indicator of different institutions in the four emerging technology fields. On average, the CNTs and Graphene Technology and Big Data Technology have a low level of depth (0.20) representing about 20% of the sub-fields with positive RAI being integrated. Other two fields hold comparatively high depth indicator. For example, in the field of Integrated Circuit Technology, the RENESAS TECH CORP (JP) has high value (0.60), TEXAS INSTRUMENTS INC (US) and LSI LOGIC CORP (US) also have high values. The RENESAS TECH CORP (JP) has a positive specialization in six sub-fields: Annealing Technology, Cleaning Technology, Doping Technology, Packaging Technology, Thin Film Deposition Technology and Thin Film Epitaxy Technology. TEXAS INSTRUMENTS INC is integrated in Doping Technology, Interconnect Technology, Packaging Technology, Thin Film Deposition Technology and Thin Film Epitaxy Technology. LSI LOGIC CORP (US) exhibits a fairly clear integrated profile in Cleaning Technology, Interconnect Technology, Planarization Technology, Thin Film Deposition Technology and Thin Film Epitaxy Technology. And for 3D Printing Technology, CHILDRENS MEDICAL CENTER (US), HEWLETT PACKARD DEVELOPMENT CO (US) and SOLIDICA INC (US) show good performance in integration. The integrated sub-fields of HEWLETT PACKARD DEVELOPMENT CO (US) are Filum Melt Bonding Technology, Plate Laminated Technology, Powder/Granular Materials Melt Bonding Technology, Spray Bonding Technology and Wire Melt Bonding Technology.

Overall, from a methodological perspective, we should point out that the depth indicator employed in this section makes it possible to discriminate between groups in a more straightforward way than the breadth indicators calculated above. Specially, the depth indicator is not biased by the size of the patenting activity of a group, and it provides a better proxy for the strategic orientation of one institution. Institutions in the emerging fields of CNTs and Graphene Technology and Big Data Technology should improve the integration level. And some famous institutions like 3D SYSTEMS INC (US) and 3M INNOVATIVE PROPERTIES CO (US) in 3D Printing Technology fields have a very high number of patents and citations, but have quite few integrated fields, while 3D SYSTEMS INC focused only on curing technology and NANOGEN INC (US) in bioprinting technology. The similar situation also happens in the field of Integrated Circuit Technology.

TABLE 4 THE DEPTH OF EMERGING TECHNOLOGY IN DIFFERENT INSTITUTIONS

CNTs and Graphene Technology	Depth	Integrated Circuit Technology	Depth	3D Printing Technology	Depth	Big Data Technology	Depth
UNIV NORTH CAROLINA (US)	0.20	IBM (US)	0.30	NANOGEN INC (US)	0.11	IBM (US)	0.33
UNIV LELAND STANFORD JUNIOR	0.20	MICRON TECHNOLOGY INC	0.40	3D SYSTEMS INC (US)	0.33	TM SF MEDIA HOLDINGS L L C (US)	0.22
CALIFORNIA INST OF TECHN (US)	0.10	MOTOROLA INC (US)	0.40	CHILDRENS MEDICAL CENTER (US)	0.56	EMC CORP (US)	0.44
TOSHIBA KK (JP)	0.20	TEXAS INSTRUMENTS INC (US)	0.50	3M INNOVATIVE PROPERTIES CO (US)	0.44	SIEBEL SYSTEMS INC (US)	0.22
JANG JIN (US)	0.20	TAIWAN SEMICONDUCTOR MFG	0.30	HEWLETT PACKARD DEVELOPMENT Company L.P. (US)	0.56	UNIV PITTSBURGH (US)	0.33
UNIV TSINGHUA (CN)	0.40	LSI LOGIC CORP (US)	0.50	SOLIDICA INC (US)	0.56	HIVE GROUP (US)	0.33
ILJIN NANOTECH CO LTD (US)	0.10	LUCENT TECHNOLOGIES INC (US)	0.30	REGENTS UNIVERSITY TEXAS SYSTE (US)	0.44	HITACHI LTD (JP)	0.33
UNIV CALIFORNIA	0.20	ADVANCED MICRO DEVICES INC (US)	0.50	INTERPORE CROSS INTERNAT (US)	0.11	RETAIL PIPELINE INTEGRATION GR (US)	0.22
UNIV NORTH CAROLINA CHAPEL HIL (US)	0.10	RENESAS TECH CORP (JP)	0.60	NUONICS INC (US)	0.11	COGNEX TECH & INVESTMENT CORP (US)	0.22
DU PONT (US)	0.10	TRUSI TECHNOLOGIES LLC (US)	0.10	BOUCHERIE NV G B (BE)	0.11	HEWLETT PACKARD DEVELOPMENT CO (US)	0.22
Average	0.20	Average	0.39	Average	0.33	Average	0.29

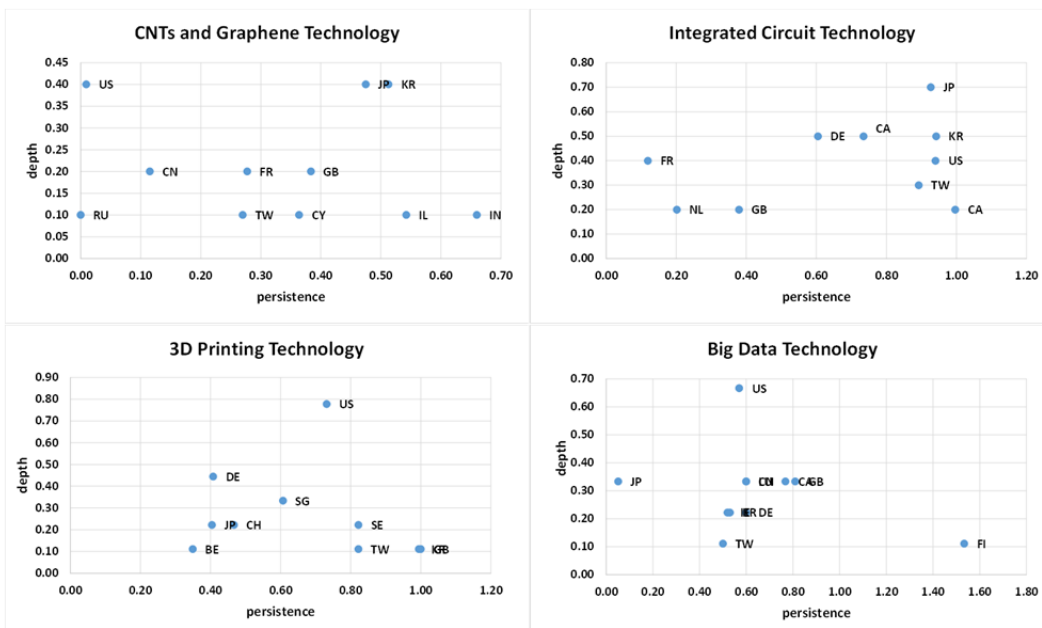

Figure 1. The specialization and integration state of countries

B. The country level analysis

The country level analysis aims to identify and operationalize at the relevant dimensions that make comparison of the emerging technology in different countries a meaningful exercise. The attention is not only paid on examining whether each country's stable technological pathway but also the sub-fields integration.

Similarly, the indicator depth presented above is used to try to capture the level of integration of countries in the four emerging technology fields. The top 10 cited times countries were chosen to do the analysis. If the country considered has a relative specialization (RAI>0) in five sub-fields of one technology field, then the country could be defined as integrated in that technology field (numerator). The denominator is the number of the sub-fields. With the aim of examining trends in the evolution of countries (persistence), the breadth of the sub-fields are compared in the two periods (1995-2000 and 2008-2013).

From Fig.1, we can draw the conclusion that in the field of **CNTs and Graphene Technology**, Korea combines high level of both depth and persistence. India and Italy show strong technology persistence and weak technology depth. On the contrary, the US indicates strong technology depth and weak technology persistence showing that the US has strong integration in the sub-fields in CNTs and Graphene Technology. Russia and China illustrate both low level of persistence and depth. It is advisable that the two countries should firstly improve the technology specialization in sub-fields of CNTs and Graphene Technology and then toward technology integration. In the field of **Integrated Circuit Technology**, Japan, France and the US show good performance on the indicator of depth and persistence. Taiwan indicates strong technology persistence and weak technology depth. The other countries should improve their technology specialization and integration. In the field of **3D Printing Technology**, the index of persistence of most countries is high, while the indicator of depth of these countries are quite low showing that most countries' technology pathway is steady but the level of technology integration is poor. In the field of **Big Data Technology,** the situation is similar to 3D Printing Technology. Japan shows poor performance on the indicator of persistence. The US combines high level of both depth and persistence.

Overall, it is fairly apparent that the US combines high levels of both technology integration and technology persistence in the emerging technology fields except the CNTs and Graphene technology. Korea, despite with a high level of persistence, shows low depth over time. Neither France nor Germany exhibits high level of integration, the persistence of technology of Germany is more stable. Japan and England are somewhere in between. China appears to be high level of persistence in Big Data Technology field, but exhibits low level of persistence and depth in other technology fields.

IV. CONCLUSIONS

This study simultaneously looks at the related processes of specialization and integration in the four emerging technology fields in the worldwide. Many have stressed that emerging technology is generated via a process of progressive specialization, with new fields of technology developing out of pre-existing fields. The indicator of persistence and depth of emerging technologies are analyzed from the perspective of institution and country in this paper. And the conclusions are as follows,

From the view of institution, some companies (e.g. Siebel Systems INC in Big Data Technology) put emphasis on specialization, it is recommended to put emphasis on integrated development for long-term consideration. Some companies (e.g. Micron Technology INC) involved in various fields, but did not highlight the certain sub-field. It is advisable for them to do more efforts in specialized sub-field to improve productivity. On the perspective of technology fields, some fields (e.g. CNTs and Graphene Technology) are more professional, while other technology field (Integrated Circuit Technology) paid attention on integration. The reason may due to the technological development time. From the side of country, specialization and integration of different countries behave differently in four emerging technology fields. China appears to have high level of persistence in Big Data Technology field, but exhibits low level of persistence and depth in other technology fields. It is advisable to improve the specialization level in CNTs and Graphene Technology and Big Data Technology and integration standard in Integrated Circuit Technology and 3D Printing Technology.

The research conclusion is also applicable for all the related countries and institutions to make technology development strategy and policy. A limitation of this study is that specialization and integration patterns could be reflected by many other indicators and patent statistic is merely one reflection form. This study just analyzes four emerging technology development from the perspective of patent statistic, we would like to continue the comprehensive analysis with the other data indicators and in more emerging technology fields.

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REFERENCES

[1] Aboutalebi S H, Jalili R, Esrafilzadeh D.J.; "High-performance multifunctional graphene yarns: toward wearable all-carbon energy storage textiles," *ACS nano*, vol. 8, pp. 2456-2466, 2014.

[2] Al-Youbi A O, de la Fuente J L G, Pérez-Alonso F J.J.; "Effects of multiwalled carbon nanotube morphology on the synthesis and electrocatalytic performance of Pt supported by multiwalled carbon

nanotubes," *Applied Catalysis B: Environmental*, vol. 150, pp.21-29, 2014.

[3] Balda M C, Furubayashi T, Nakata T.J.; "Integration of WTE technologies into the electrical system for low-carbon growth in Venezuela," *Renewable Energy*, vol. 86, pp.1247-1255, 2016.

[4] Brusoni S, Prencipe A, Pavitt K.J.; "Knowledge specialization, organizational coupling, and the boundaries of the firm: why do firms know more than they make?" *Administrative science quarterly*, vol. 46, pp.597-621, 2001.

[5] Brusoni S, Geuna A, M.; *Specialisation and integration Handbook of quantitative science and technology research*. Netherlands: Springer Netherlands, 2005.

[6] Casado R, Younas M.J.; "Emerging trends and technologies in big data processing," *Concurrency and Computation: Practice and Experience*, vol. 27, pp. 2078-2091, 2015.

[7] Chiappini R.J.; "Persistence vs. mobility in industrial and technological specializations: evidence from 11 Euro area countries," *Journal of Evolutionary Economics*, vol.24, pp. 159-187, 2014.

[8] Conant J B, M. *Harvard case histories in experimental science*, Cambridge, MA: Harvard University Press, 1964.

[9] Granstrand O, Patel P, Pavitt K.J.; "Multi-technology corporations: why they have" distributed" rather than" distinctive core" competencies," *California management review*, vol.39, pp. 8, 1997.

[10] Jaffe A B.J.; Technological opportunity and spillovers of R&D: evidence from firms' patents, profits and market value. 1986.

[11] Jiang Y, Sun R, Wang S, et al. Development of a New Wire Bonding Technology on Integrated Circuit Devices[C]//ASME 2009 Inter PACK Conference collocated with the ASME 2009 Summer Heat Transfer Conference and the ASME 2009 3rd International Conference on Energy Sustainability. American Society of Mechanical Engineers, 2009: 1-7.

[12] Kapoor R.J.; "Persistence of integration in the face of specialization: How firms navigated the winds of disintegration and shaped the architecture of the semiconductor industry," *Organization Science*, vol.24, pp. 1195-1213, 2013.

[13] Koten, J., "A revolution in the making. Wall STR.J", Retrieved 2/9/03 World Wide Web, http://wsj.com/news/articles/SB1000142412788732406330457852281268472 2382

[14] Lawrence P R, Lorsch J W, M.; *Garrison J S. Organization and environment: Managing differentiation and integration*, Boston, MA: Division of Research, Graduate School of Business Administration, Harvard University, 1967.

[15] Lall S.J.; "The Technological structure and performance of developing country manufactured exports, 1985 - 98," *Oxford development studies*, vol.28, pp. 337-369, 2000.

[16] Loasby B J.J.; "The significance of Penrose's theory for the development of economics," *Contributions to Political Economy*, vol.18, pp.31-45, 1999.

[17] Meliciani V.J.; "The Globalizing Learning Economy: D. Archibugi, B. Lundvall (Eds.)," *Oxford University Press, Oxford*, vol.40, pp. 307, 2002.

[18] Nesta L.M.; *Cohérence des Bases de Connaissances et Changement Technique: une Analyse des Firmes de Biotechnologies de 1981 à 1997*. ANRT, Université Pierre Mendes France (Grenoble II), 2001.

[19] Prencipe A. J.; "Breadth and depth of technological capabilities in CoPS: the case of the aircraft engine control system," *Research Policy*, vol. 29, pp. 895-911, 2000.

[20] Soete L, Wyatt S.J.; "The use of foreign patenting as an internationally comparable science and technology output indicator," *Scientometrics*, vol.5, pp. 31-54, 1983.

[21] White T. Hadoop, M; *The definitive guide*, US: O'Reilly Media, Inc., 2012.

[22] Wohlers T, M; *Wohlers report 2012*, US: Wohlers Associates, Inc, 2012.

[23] Zhu H, Xia J, Makino S.J.; "How do high-technology firms create value in international M&A? Integration, autonomy and cross-border contingencies," *Journal of World Business*, 2015.