

Assessing coreness and intermediarity of technology sectors using patent co-classification analysis: the case of Korean national R&D

Hyunseok Park · Janghyeok Yoon

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Abstract Rapid technological advancements and increasing research and development (R&D) costs are making it necessary for national R&D plans to identify the coreness and intermediarity of technologies in selecting projects and allocating budgets. Studies on the coreness or intermediarity of technology sectors have used patent citations, but there are limitations to dealing with patent data. The limitations arise from the most current patents and patents that do not require citations, e.g. Korean patents. Further, few or no studies have simultaneously considered both coreness and intermediarity. Therefore, we propose a patent co-classification based method to measure coreness and intermediarity of technology sectors by incorporating the analytic network process and the social network analysis. Using IPC co-classifications of patents as technological knowledge flows, this method constructs a network of directed knowledge flows among technology sectors and measures the long-term importance and the intermediating potential of each technology sector, despite the limitations of patent-based analyses. Considering both coreness and intermediarity, this method can provide more detailed and essential knowledge for decision making in planning national R&D. We demonstrated this method using Korean national R&D patents from 2008 to 2011. We expect that this method will help in planning national R&D in a rapidly evolving technological environment.

Keywords Patent analysis · Analytic network process (ANP) · Social network analysis (SNA) · National R&D investment

JEL Classification C63 · C82 · O32

H. Park

Graduate School of Technology and Innovation Management, Pohang University of Science and Technology, 77 Cheongam-ro, Nam-gu, Pohang 790-784, Republic of Korea
e-mail: howgood@postech.ac.kr

J. Yoon (✉)

Department of Industrial Engineering, Konkuk University, 120 Neungdong-ro, Gwangjin-gu, Seoul 143-701, Republic of Korea
e-mail: janghyoon@konkuk.ac.kr

Introduction

There is no doubt that research and development (R&D) is critical to secure promising technologies and remain technologically competitive in today's knowledge-based economies (Jaffe 1986). Therefore, many national governments have been making large investments into government-supported R&D (national R&D) programs to stimulate the development of original and convergent technologies, overcome "market failures", and allow a nation to compete globally (Hsu et al. 2009; Choi et al. 2009; Fier et al. 2006).

However, because the funds available for R&D are limited and the costs of these programs increase, the technical and economic validity of R&D programs need to be assessed so that projects can be selected and budget can be allocated. Because national R&D, which requires large costs over a long time, generally involves a high risk, each technology sector in a national R&D plan should be evaluated to optimize the effectiveness and efficiency of a national R&D investment (Choi et al. 2009; Gu et al. 2009). Regarding the purposes of national R&D, the coreness, which is defined as the degree of the scientific or technological impacts of a technology sector on its own sector and other sectors in a technological knowledge flow (TKF) network among sectors, should be evaluated to confirm the technical validity (Galende and de la Fuente 2003; Holbrook and Jang 2006) and the intermediarity, which is defined to be the degree of a technology sector's bridging and brokerage ability as a knowledge intermediary that facilitates knowledge flows between sectors in a TKF network among sectors, should be evaluated to confirm the economic validity (Holbrook and Jang 2006; Lim and Park 2010; Yoo et al. 2007). In particular, to build a specific strategic direction of further R&D projects for a technology sector, both coreness and intermediarity should be considered at the same time. Although much research has evaluated coreness or intermediarity of technology sector separately, few studies have considered both simultaneously.

Patents, as the final results and intellectual property of R&D programs, are considered to be a good proxy for the exchange and link between technological knowledge (Zhang and Baden-Fuller 2009). In addition, many surveys have revealed that patents include more than 90 % of the latest technical information in the world, and 80 % of the information in patents has not been published in any other form (Zha and Chen 2010). Therefore, various patent-based studies have suggested ways to evaluate the coreness or intermediarity of technology sectors by measuring knowledge flows.

One method to evaluate the technological coreness or intermediarity is by analyzing patent citations. A citation-based approach is based on the idea that one patent citing another patent indicates a strong possibility that the newer patent builds upon important ideas in the older patent; a citing-cited relation indicates a knowledge flow. Studies have used citations as indications of knowledge flow to identify core technologies in the telecommunication sector (Lee et al. 2009), shape an interdisciplinary knowledge network among research areas in China (Liu et al. 2011), investigate the knowledge base dynamics of the biotechnology sector (Krafft et al. 2011), measure knowledge flows among traditional and emerging industries (Han and Park 2006), measure knowledge diffusion among technology sectors (Liu et al. 2011; Nelson 2009), identify core and emerging technologies in Taiwan (Cho and Shih 2011), and analyze the early stages of convergence (Karvonen and Kässi 2012).

Although the citation-based studies provide methods to analyze the coreness or intermediarity of technology sectors, they have some limitations. The studies may not be effective for recent patents because of citation lag (Hall et al. 2001). Also, they can never successfully deal with the patents in which citations are not mandatory, e.g. Korean and

Japanese patents. These limitations prevent experts from identifying the coreness and intermediarity of technology sectors based on the most recent patents when formulating national R&D plans.

To address these limitations, this paper proposes an integrated procedure to measure the coreness and intermediarity of technology sectors using the patent co-classification analysis. The procedure comprises (1) identifying directed TKFs among international patent classifications (IPCs) by using patent co-classification analysis; (2) constructing a TKF matrix among technology sectors by exploiting IPC-industry concordance; (3) measuring the coreness and intermediarity of technology sectors using the analytic network process (ANP) and the social network analysis (SNA); and (4) generating visual output, called a knowledge spillover portfolio map. This method can be used to analyze the coreness and intermediarity of technology sectors despite the limitations described above. In addition, the method provides a visual map that synthetically considers both dimensions of technological coreness and intermediarity. We expect that this method can be used to provide input for decision-making in the R&D investment planning process at the national level.

The organization of this paper is as follows: we present an overview of the groundwork, followed by the procedure to evaluate coreness and intermediarity of technology sectors using Korean national R&D patents from 2008 to 2011, and conclusions with further research topics.

Groundwork

The procedure proposed in this paper is based on patent co-classification, ANP, and SNA. Therefore, this section presents a brief overview of the theoretical background.

Patent co-classification analysis

Patent co-classification analysis is one method used in patent-based bibliographic studies to identify knowledge flows among technology areas from a technological perspective (Verspagen 1997). Patent co-classification is mentioned in the 1994 OECD Manual as a potential indicator of linkages among technologies (Leydesdorff 2008). Although co-classification of the IPC codes into which a patent is classified is often considered to be undirected, distinguishing the main class from supplementary classes can indicate the flow direction; in co-classification, there exists a single class that is most related and this can be generally judged as the first listed class. These two class types of a patent can be distinguished: one class for the “claimed” knowledge (“invention information”) and the other class for non-appropriable knowledge (“additional information”) (Verspagen 1997). In a patent, the claimed knowledge of an invention can be assigned to a single technology class, while other related knowledge can be classified into multiple supplementary classes. Fundamentally, the underlying idea of the patent co-classification in this paper is that the main class generates knowledge and the supplementary classes receive knowledge.

By incorporating patent co-classification analysis and patent classification-industry concordance, studies have been conducted to track the knowledge spillover of mechanical engineering technology (Patel and Pavitt 1994), to measure the amount of technological spillovers among industries using EU and US patents (Verspagen 1997), to identify the intellectual organization of PCT (Patent Cooperation Treaty) applications (Leydesdorff 2008), and to identify direct intermediating scores of industry sectors using Korean patents in the USPTO (United States Patent and Trademark Office) database (Lim and Park 2010).

Although these studies analyzed technological spillovers from a technology sector perspective, they did not address the technological importance and intermediarity of technology sectors over the long-term and from an overall network perspective.

Therefore, this paper has a differentiation in that it measures the degree of how important a technology sector is in the long-term, and how well it intermediates between other technology sectors in the whole technology sector network.

Analytic network process

ANP is a generalized form of the analytic hierarchy process (AHP), which is a theory of relative measurement with absolute scales of both tangible and intangible criteria based on expert judgment (Saaty 1996). ANP extends the AHP to problems with dependence and feedback. It allows for more complex inter-relationships among decision elements by replacing a hierarchy in the AHP with a network (Saaty 2004). The ANP identifies the importance of decision factors by constructing a network model, making pairwise comparisons and identifying priority vectors, forming and transforming a supermatrix, and identifying final priorities.

The ANP has been widely adopted to solve a variety of problems including identifying core technologies in the telecommunication sector (Lee et al. 2009; Kim et al. 2011), selecting investment projects (Aragónés-Beltrán et al. 2010; Mohanty et al. 2005), evaluating new service concepts (Lee et al. 2010), and evaluating projects and analyzing risk (Jung and Seo 2010).

In sum, the main advantage of the ANP is that it identifies the importance of decision elements based on self-influence and dependence over the long-term (Saaty 2005). Therefore, we identified the technological coreness of each technology sector by incorporating the concept to measure the importance of decision elements in the ANP and the knowledge spillovers among technology sectors.

Social network analysis

SNA is a popular method to map and measure relationships and interactions among actors including people, groups, organizations, computers, and other connected entities (Hanneman and Riddle 2005). In general, a network consists of nodes (actors) and links (relationships). In this paper, each node represents a technology sector and each link represents the amount of technological knowledge spillovers between a pair of technology sectors. Visual representation of a network provides an overall understanding of network data, and the network can be investigated in depth using various network analysis indicators such as degree, centrality and density (Scott 2000).

Among the SNA indicators, betweenness centrality is a measure of a node's global centrality in a network, and it is calculated using the number of shortest paths from all nodes to all others that pass through the node (Freeman 1977). Since the betweenness centrality can consider the relative position of nodes in a network from the whole network perspective, it is a useful measure of the road placed on the given node in the network as well as the node's importance to the network than just connectivity (Freeman 2004). In a network, the shortest geodesic path facilitates the dissemination of information and knowledge and the number of the shortest paths that pass through the given node can determine the ability of the node to function as an intermediary (Liu et al. 2011; Chen and Guan 2011).

In patent analysis, betweenness centrality has been widely adopted to identify the innovation potential of an alliance network (Gilsing et al. 2008), to identify disembodied knowledge flows among industrial sectors (Park et al. 2009), and to identify characteristics of technological properties and functions in inventive concept networks (Yoon et al. 2011).

This paper applies the concept of betweenness centrality to identify the technological intermediarity of sectors in the whole technology network.

Data

Effectively understanding evolving national R&D trends is a prerequisite to formulating governmental R&D plans, so we used a total of 20108 Korean national R&D patents that were granted from 2008 through 2011.

Since 2009, the Korean government has managed patents put out by national R&D programs, and the patents granted are accessible via the R&D intellectual property information system (www.rndip.or.kr). Although the recent policy of Korean Intellectual Property Office (KIPO) optionally recommends citations of other patents or scientific articles, we found that the national R&D patents rarely contain backward citations, and that almost of the patents are recent and have not been cited by other later patents.

These peculiarities of Korean national R&D patents that are used in this paper make it unavailable to apply the citation-based patent analysis to the patent data in analyzing TKFs. Therefore, we used the method described below to analyze the patent data.

Procedure

The proposed procedure consists of four steps (Fig. 1): (1) directed flows of technological knowledge among IPCs were measured by patent co-classification analysis, (2) a TKF matrix among technology sectors was constructed by industrial classification analysis, (3) the technological coreness and intermediarity of each sector were identified by technological coreness and intermediarity analyses, and (4) a knowledge spillover portfolio map was constructed. This section describes each step in detail.

Patent co-classification analysis

The first step for the proposed procedure is to measure the amount of TKFs among patent IPCs. A full IPC code has a section, class, subclass, main group, and sub-group (for example, A61K 11/00). Many studies, however, have exploited the 4-digit IPC code, which contains section, class, and subclass (for example, A61K), because the 4-digit IPC code shows sufficient technological characteristics of fields related to a patent (Guan and He 2007; Chen et al. 2010; Wang et al. 2011). Therefore, this step distinguishes the 4-digit main IPC from 4-digit supplementary IPCs.

Each patent can be classified into one IPC as the main invention area, 4-digit IPCs after eliminating duplicated ones can represent knowledge flows from a main IPC (knowledge-generating sector) to multiple supplementary IPCs (knowledge-receiving sectors). A sample of 5 patents (from P1 to P5) have 5, 4, 4, 4, and 3 IPCs including a main IPC, thus these technology classes can be used to construct a TKF network (Fig. 2).

This process identifies all TKFs among IPCs. By analyzing Korean national R&D patents, we found a total of 510 IPCs (detailed technology classes) and 8910 TKFs among

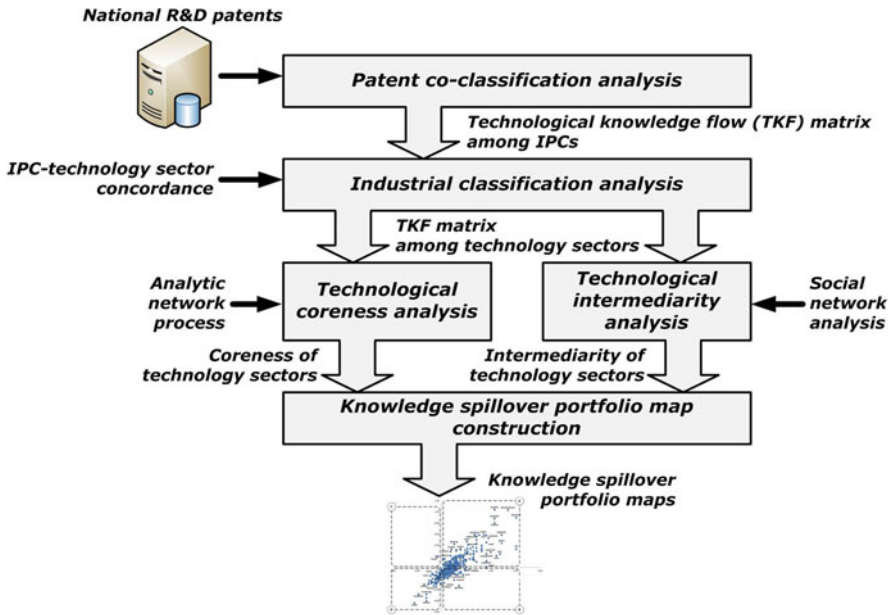


Fig. 1 Overall procedure

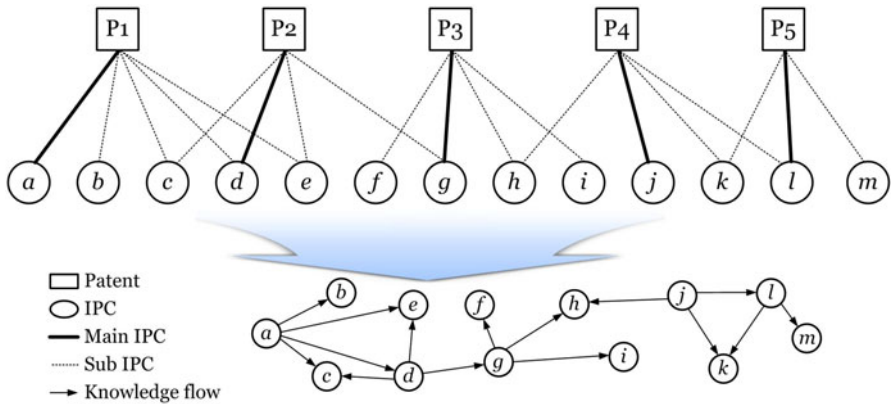


Fig. 2 Identification of directed technological knowledge flows among IPCs. Note e.g. P1 is classified into main IPC *a* and sub-IPC *b*, *c*, *d* and *e* and generates 4 knowledge flows that from *a* to *b*, *c*, *d* and *e*

IPCs (spread from one technology class to the other different technology classes) (Table 1); each cell in the matrix for TKFs among IPCs, TKF_IPC_{ij} , is the number of patents that are classified in mainly IPC_i and supplementary IPC_j .

Industrial classification analysis

Inter-industrial knowledge flows are considered a principle determinant of the ability of a nation to compete (Park et al. 2009; Park and Kim 1999), thus this step aims at identifying

Table 1 Part of technological knowledge flows among IPCs in Korean national R&D (2008–2011)

	A01H	A21D	A23B	A23C	A23D	A23F	A23G	A23J	A23K	A23L	A23P	C12C	C12G	C12J	A24D	D04H	D06C	D06M	D06N	D06P	D06Q
A01H	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A21D	0	9	0	0	0	0	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0
A23B	0	0	32	0	0	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0
A23C	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23D	0	0	0	0	8	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
A23F	0	0	0	0	0	13	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
A23G	0	0	0	0	0	0	6	0	0	1	1	0	0	0	0	0	0	0	0	0	0
A23J	0	0	0	0	0	0	0	4	0	3	0	0	0	0	0	0	0	0	0	0	0
A23K	0	0	0	0	0	0	0	0	40	6	0	0	0	0	0	0	0	0	0	0	0
A23L	1	2	6	3	1	5	3	0	0	267	4	0	0	0	0	0	0	0	0	0	0
A23P	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0
C12C	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0
C12G	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0
C12J	0	0	0	0	0	0	0	0	0	1	0	0	5	0	0	0	0	0	0	0	0
A24D	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
D04H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	1	0	0	0	0
D06C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0
D06M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	46	0	2	1	0
D06N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	0	0	0
D06P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	10	0
D06Q	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A41D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A41F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A43B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A43C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B27D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B27H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B27M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1 continued

	A01H	A21D	A23B	A23C	A23D	A23F	A23G	A23J	A23K	A23L	A23P	C12C	C12G	C12J	A24D	D04H	D06C	D06M	D06N	D06P	D06Q	
B27N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
E04G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
B41M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
B42D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D21C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D21H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
D21J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C10G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C10L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
G01V	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
B01J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
B09B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
B09C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
B29B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C01B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	A41D	A41F	A43B	A43C	B27D	B27H	B27M	B27N	E04G	B41M	B42D	D21C	D21H	D21J	C10G	C10L	G01V	B01J	B09B	B09C	B29B	C01B
A01H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A21D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23K	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A23P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1 continued

	A41D	A41F	A43B	A43C	B27D	B27H	B27M	B27N	E04G	B41M	B42D	D21C	D21H	D21J	C10G	C10L	G01V	B01J	B09B	B09C	B29B	C01B	
C12C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A24D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D04H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D06C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D06M	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D06N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D06P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D06Q	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A41D	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A41F	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A43B	0	8	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A43C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B27D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B27H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B27M	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B27N	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E04G	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B41M	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
B42D	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
D21C	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0
D21H	0	0	0	0	0	0	0	0	0	0	1	16	0	0	0	0	0	0	0	0	0	0	0
D21J	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
C10G	0	0	0	0	0	0	0	0	0	0	0	0	0	27	9	0	2	0	0	0	0	0	0
C10L	0	0	0	0	0	0	0	0	0	0	0	0	3	31	0	1	5	0	0	0	0	0	0
G01V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0
B01J	0	0	0	0	0	0	0	0	0	0	0	0	7	1	1	0	325	0	0	0	1	0	41

Table 1 continued

	A41D	A41F	A43B	A43C	B27D	B27H	B27M	B27N	E04G	B41M	B42D	D21C	D21H	D21J	C10G	C10L	G01V	B01J	B09B	B09C	B29B	C01B
B09B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	1	1	0
B09C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0
B29B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	15	0
C01B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	176

the amount of TKFs among industrial sectors by exploiting IPC-ISIC (International Standard Industrial Classification) concordance suggested by the Fraunhofer Institute for Systems and Innovation Research (ISI), Germany, Observatoire des Sciences et des Techniques (OST), France, and Science and Policy Research Unit (SPRU), UK (Schmoch et al. 2003) (Table 8 in Appendix); although there exists several concordances between patent classification and industrial sector (Grupp and Schmoch 1992; Evenson and Puttnam 1988; Kortum and Putnam 1997; Verspagen et al. 1994; Johnson 2002), we selected the ISI–OST–SPRU concordance in that this is more recently-developed and industry-oriented classification than others. The ISI–OST–SPRU concordance includes the linkage of 625 four-digit IPC classes to 43 technological sectors defined by the product manufacturing characteristics according to the main focus of the IPC (Schmoch et al. 2003). Fractional associations are not allowed, so each IPC subclass is linked to one of the sectors (Fig. 3).

As a result of the analysis of Korean national R&D patents, each IPC subclass was assigned to 1 of the 43 fields, and finally inter-industrial TKFs could be generated as a matrix (Table 2); the TKF matrix includes inter-sector influences as well as self-influences. Each cell of the matrix, TKF_IND_{ij} , indicates the number of patents whose main IPC is assigned to the industrial sector i and one of supplementary IPCs is assigned to the sector j at the same time. Steps 4.3 and 4.4 use the influences to calculate the technological importance of each sector using the ANP and to identify the technological intermediarity of each sector using the betweenness centrality of the SNA.

Technological coreness analysis

The ANP is known as a useful method to identify priority or importance of decision factors from a long-term view using a network model (Saaty 2005). The TKF matrix from the previous step represents a network model and in addition it includes dependence and feedback (self-influence) among technological sectors. Therefore, by adopting the “limiting priority” concept in the ANP (Saaty 2004), this step identifies the technological importance of technology sectors taking both direct and indirect dependences into

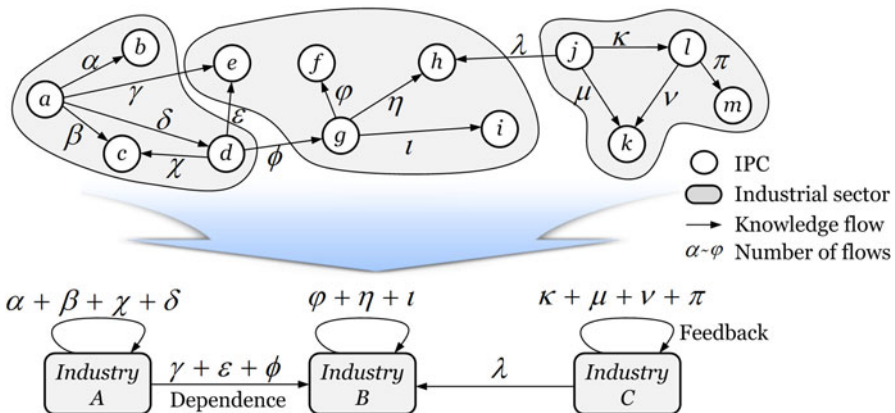


Fig. 3 Identification of technological knowledge flows among industries. Note IPC a, b, c and d are assigned to Industry A, IPC e, f, g, h and i are assigned to Industry B, and IPC j, k, l and m are assigned to Industry C

Table 2 Technological knowledge flows among technological sectors in Korean national R&D (2008–2011)

	C01	C02	C03	C04	C05	C06	C07	C09	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
C01	516	0	0	0	0	0	0	0	2	0	0	25	0	0	0	2	0	0	0	0	0	7	0
C02	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C03	0	0	94	1	0	0	0	0	1	0	0	0	1	0	7	0	3	0	0	0	0	0	0
C04	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C05	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C06	0	0	0	0	0	31	0	0	1	0	1	0	0	0	0	0	5	0	0	0	0	0	0
C07	0	0	0	0	0	0	29	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0
C09	1	0	0	0	0	0	0	94	16	0	0	3	0	1	0	0	1	0	3	0	1	0	1
C10	1	0	1	0	1	0	0	15	2782	1	0	65	1	6	2	13	25	6	90	2	98	5	5
C11	0	0	0	0	0	0	0	0	1	90	0	4	0	0	0	1	0	0	0	0	0	1	0
C12	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
C13	80	0	0	0	0	0	0	5	22	16	0	4286	1	1	0	0	0	0	4	0	2	13	0
C14	0	0	1	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0
C15	0	0	1	0	0	0	1	0	3	0	0	0	0	70	0	0	0	0	2	0	1	0	0
C16	0	0	1	0	0	0	0	0	1	0	0	0	0	0	36	0	3	0	1	0	0	0	0
C17	0	0	0	0	0	1	0	0	11	0	0	0	0	0	0	220	4	5	10	0	1	1	3
C18	0	0	0	0	0	5	1	0	13	0	0	0	0	1	0	0	503	11	6	2	0	0	7
C19	0	0	0	1	0	1	0	0	9	0	0	0	0	0	0	14	16	409	4	2	6	0	4
C20	0	0	0	0	0	3	1	0	94	0	0	1	0	0	0	9	23	17	869	3	9	0	2
C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	337	4	0	2
C22	0	0	0	0	0	0	0	0	42	0	0	1	0	0	0	4	4	1	7	7	712	2	2
C23	4	0	0	0	0	0	0	0	1	0	0	6	0	0	0	0	2	1	0	1	4	221	1
C24	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	5	10	8	9	3	0	558
C25	3	0	8	0	1	3	2	2	15	0	0	0	1	1	2	12	15	13	10	1	8	3	8
C26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
C27	5	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	2	7	0	0

Table 2 continued

	C01	C02	C03	C04	C05	C06	C07	C09	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
C28	0	0	0	1	0	0	5	0	6	0	0	5	0	1	0	1	5	1	7	1	2	0	8
C29	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	6	1	0	0
C30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
C31	0	0	0	0	0	0	1	0	29	0	0	1	0	0	0	1	3	0	3	2	2	0	0
C32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0
C33	0	0	0	0	0	0	0	0	9	0	0	0	1	0	1	1	1	2	3	2	1	0	2
C34	0	0	0	0	0	0	0	0	18	0	0	0	0	0	3	8	16	56	3	3	0	4	4
C35	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	3	2	2	3	0	6	6
C36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
C37	1	0	0	3	0	0	16	0	1	0	0	16	0	0	3	0	0	3	0	4	5	8	8
C38	1	0	0	0	0	0	76	0	5	12	0	76	0	0	1	1	2	8	6	10	1	4	4
C39	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2	0	0	1	1
C40	0	0	0	0	0	0	1	0	8	0	0	1	0	0	4	3	0	3	0	2	0	1	1
C41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C42	0	0	0	0	0	0	0	1	5	0	0	0	0	0	0	2	0	5	23	11	0	6	6
C43	0	0	0	1	0	0	0	0	1	0	0	0	0	0	6	1	1	6	8	6	0	3	3
C44	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1	1	0	0	0
C25		C26	C27	C28	C29	C30	C31	C32	C33	C34	C35	C36	C37	C38	C39	C40	C41	C42	C43	C44			
C01	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C03	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C04	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
C05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C06	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C07	2	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0

Table 2 continued

	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	C35	C36	C37	C38	C39	C40	C41	C42	C43	C44
C09	6	0	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	1	0
C10	27	0	9	16	0	0	38	0	6	51	3	0	18	12	0	13	0	3	1	0
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C13	0	0	0	3	0	0	0	0	0	4	0	0	21	55	0	0	0	0	0	0
C14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
C15	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
C16	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C17	6	0	0	4	0	0	0	0	0	0	0	0	0	5	0	4	0	1	4	0
C18	5	0	2	1	0	1	1	2	0	5	3	0	0	1	0	2	0	0	0	2
C19	14	0	0	4	0	1	0	1	1	15	0	0	0	2	0	1	0	0	0	0
C20	14	0	1	1	0	1	4	1	1	45	3	0	7	11	2	7	0	1	4	0
C21	0	0	0	2	0	0	0	0	0	1	1	0	0	1	0	0	0	16	6	1
C22	13	0	5	4	1	0	2	0	1	9	1	0	6	8	3	0	0	4	5	1
C23	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
C24	14	0	1	8	4	0	0	0	3	4	4	2	4	2	5	1	0	27	1	7
C25	698	0	1	5	2	0	1	0	0	15	2	0	9	13	0	1	0	3	2	0
C26	0	36	0	0	0	0	0	0	0	0	1	0	1	3	0	0	0	0	5	1
C27	6	0	288	11	0	0	1	4	1	39	8	0	1	1	0	4	0	4	0	1
C28	7	0	26	3319	0	5	0	4	20	56	240	70	19	32	5	23	0	6	1	3
C29	1	0	0	2	229	0	0	0	3	6	4	0	3	2	0	1	0	2	0	0
C30	0	0	0	0	0	117	1	1	1	3	1	1	0	1	0	1	0	2	0	0
C31	5	0	0	0	1	0	521	0	1	6	1	0	0	5	1	1	0	13	1	0
C32	0	0	3	0	0	0	0	58	0	2	0	0	0	0	0	2	0	0	0	0
C33	1	0	1	45	3	5	0	1	686	4	40	10	6	28	13	3	0	12	9	3
C34	13	1	20	37	6	0	4	1	4	2805	17	3	4	28	2	38	0	0	0	0

Table 2 continued

	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	C35	C36	C37	C38	C39	C40	C41	C42	C43	C44
C35	3	0	3	209	1	5	5	0	17	31	5138	30	7	20	5	13	0	6	2	1
C36	1	0	0	67	0	0	0	0	8	6	60	1178	1	2	1	16	0	0	0	1
C37	6	0	1	23	0	2	2	0	5	6	11	0	1144	21	2	3	0	6	1	9
C38	13	2	1	47	3	1	4	0	21	51	25	3	25	2193	27	23	0	18	7	1
C39	1	0	0	1	0	1	0	0	14	6	6	1	0	27	154	1	0	1	1	1
C40	0	0	0	37	0	0	0	3	1	28	15	7	1	21	2	435	0	0	1	0
C41	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	6	0	0	0
C42	3	0	0	1	6	0	3	1	11	5	8	1	0	20	3	0	0	691	5	3
C43	4	2	0	0	2	0	0	1	2	0	1	0	0	7	1	0	0	12	279	1
C44	1	0	0	4	0	0	0	0	0	0	0	0	5	2	0	1	0	0	1	109

consideration. This is the basic idea of identifying the coreness of technological sectors in this paper.

For the ANP analysis of Korean national R&D, this step first generated a network model (Fig. 4) that includes the dependence and self-influence of technology sectors. However, nodes that are impossible to leave the nodes or do not interact with other nodes impede the ANP analysis. In the network model, these nodes are C2 (tobacco products), C5 (leather articles), and C41 (watches, clocks). C2 does not interact with any other nodes, technological knowledge does not flow from C5 to any other node, and technological knowledge never enters C41 (Fig. 4). Obviously, each of the three nodes has relatively weak knowledge flows to other nodes, so these three nodes were eliminated from the coreness analysis.

ANP analysis requires pairwise comparisons between technology sectors using a scale from 1 to 9 to obtain priority vectors. In our process, however, pairwise comparisons are not necessary because the initial importance of a node can be directly measured by the TKFs corresponding to dependence and self-influence. By exploiting the concept of a previous study using the citation-based ANP network approach (Lee et al. 2009), we constructed a priority matrix W containing priority column vectors (Table 3) and found a

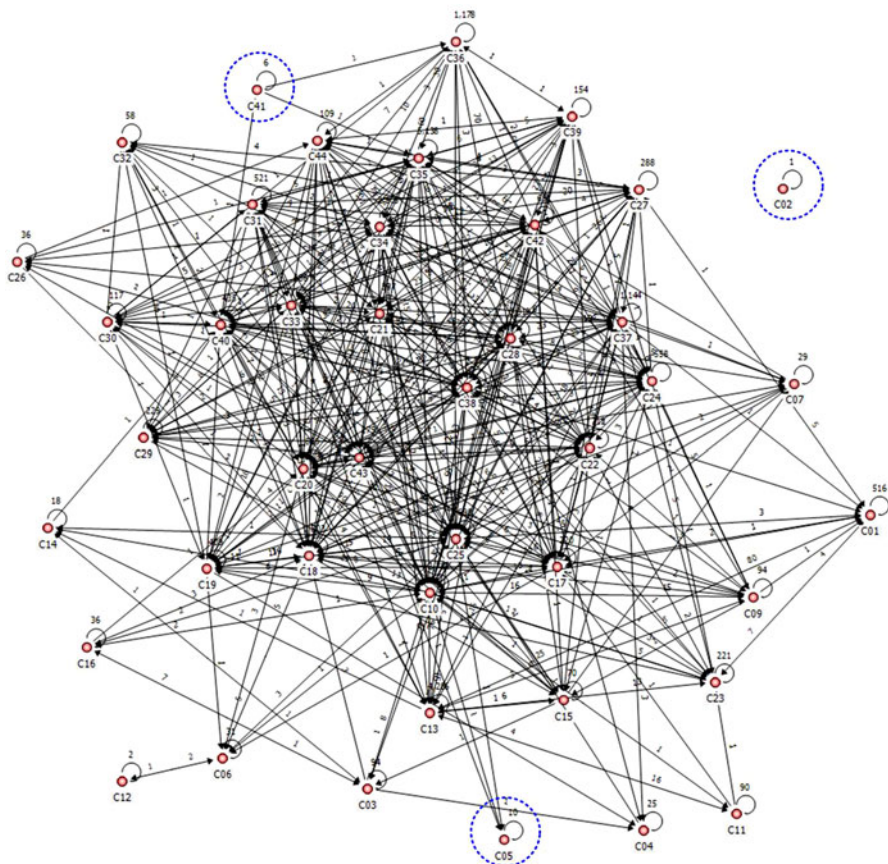


Fig. 4 A network model for ANP analysis of Korean national R&D

Table 3 Priority matrix of technological sectors in Korean national R&D (2008–2011)

	C01	C03	C04	C06	C07	C09	C10	C11	C12	C13	C14	C15
C01	0.843	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.006	0.000	0.000
C03	0.000	0.887	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.045	0.000
C04	0.000	0.000	0.806	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C06	0.000	0.000	0.000	0.674	0.000	0.000	0.000	0.000	0.333	0.000	0.000	0.000
C07	0.000	0.000	0.000	0.000	0.725	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C09	0.002	0.000	0.000	0.000	0.000	0.770	0.005	0.000	0.000	0.001	0.000	0.012
C10	0.002	0.009	0.000	0.000	0.000	0.123	0.893	0.009	0.000	0.014	0.045	0.072
C11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.841	0.000	0.001	0.000	0.000
C12	0.000	0.000	0.000	0.043	0.000	0.000	0.000	0.000	0.667	0.000	0.000	0.000
C13	0.131	0.000	0.000	0.000	0.000	0.041	0.007	0.150	0.000	0.955	0.045	0.012
C14	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.818	0.000
C15	0.000	0.009	0.000	0.000	0.025	0.000	0.001	0.000	0.000	0.000	0.000	0.843
C16	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C17	0.000	0.000	0.000	0.022	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
C18	0.000	0.000	0.000	0.109	0.025	0.000	0.004	0.000	0.000	0.000	0.000	0.012
C19	0.000	0.000	0.032	0.022	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000
C20	0.000	0.000	0.000	0.065	0.025	0.000	0.030	0.000	0.000	0.000	0.000	0.000
C21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C22	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000
C23	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
C24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012
C25	0.005	0.075	0.000	0.065	0.050	0.016	0.005	0.000	0.000	0.000	0.045	0.012
C26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C27	0.008	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
C28	0.000	0.000	0.032	0.000	0.125	0.000	0.002	0.000	0.000	0.001	0.000	0.012
C29	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000

Table 3 continued

	C01	C03	C04	C06	C07	C09	C10	C11	C12	C13	C14	C15
C30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C31	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000
C32	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C33	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.012
C34	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000
C35	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
C36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C37	0.002	0.000	0.097	0.000	0.025	0.000	0.000	0.000	0.000	0.004	0.000	0.000
C38	0.002	0.000	0.000	0.000	0.000	0.041	0.004	0.000	0.000	0.017	0.000	0.000
C39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C40	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000
C42	0.000	0.000	0.000	0.000	0.000	0.008	0.002	0.000	0.000	0.000	0.000	0.000
C43	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C01	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.027	0.000	0.006	0.000	0.003	0.000	0.000	0.000
C03	0.149	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000
C04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
C06	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
C07	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
C09	0.000	0.000	0.002	0.000	0.003	0.000	0.001	0.000	0.002	0.007	0.000	0.000	0.000	0.000	0.000
C10	0.043	0.043	0.039	0.012	0.081	0.005	0.109	0.019	0.008	0.030	0.000	0.025	0.004	0.000	0.000
C11	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C13	0.000	0.000	0.000	0.000	0.004	0.000	0.002	0.050	0.000	0.000	0.000	0.000	0.001	0.000	0.000

Table 3 continued

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C15	0.000	0.000	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007
C16	0.766	0.000	0.005	0.000	0.001	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000
C17	0.000	0.724	0.006	0.010	0.009	0.000	0.001	0.004	0.005	0.007	0.000	0.000	0.001	0.000	0.000
C18	0.000	0.000	0.791	0.022	0.005	0.005	0.000	0.000	0.011	0.006	0.000	0.006	0.000	0.000	0.007
C19	0.000	0.046	0.025	0.816	0.004	0.005	0.007	0.000	0.006	0.016	0.000	0.000	0.001	0.000	0.007
C20	0.000	0.030	0.036	0.034	0.777	0.007	0.010	0.000	0.003	0.016	0.000	0.003	0.000	0.000	0.007
C21	0.000	0.000	0.000	0.002	0.004	0.799	0.004	0.000	0.003	0.000	0.000	0.000	0.001	0.008	0.000
C22	0.000	0.013	0.006	0.002	0.006	0.017	0.790	0.008	0.003	0.015	0.000	0.014	0.001	0.004	0.000
C23	0.000	0.000	0.003	0.002	0.000	0.002	0.004	0.853	0.002	0.002	0.000	0.000	0.000	0.000	0.000
C24	0.000	0.010	0.008	0.020	0.007	0.021	0.003	0.000	0.876	0.016	0.000	0.003	0.002	0.015	0.000
C25	0.043	0.039	0.024	0.026	0.009	0.002	0.009	0.012	0.013	0.779	0.000	0.003	0.001	0.008	0.000
C26	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.878	0.000	0.000	0.000	0.000
C27	0.000	0.003	0.000	0.000	0.000	0.005	0.008	0.000	0.000	0.007	0.000	0.793	0.003	0.000	0.000
C28	0.000	0.003	0.008	0.002	0.006	0.002	0.002	0.000	0.013	0.008	0.000	0.072	0.862	0.000	0.036
C29	0.000	0.000	0.000	0.000	0.000	0.014	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.881	0.000
C30	0.000	0.007	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.848
C31	0.000	0.003	0.005	0.000	0.003	0.005	0.002	0.000	0.000	0.006	0.000	0.000	0.000	0.004	0.000
C32	0.000	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000
C33	0.000	0.003	0.002	0.004	0.003	0.005	0.001	0.000	0.003	0.001	0.000	0.003	0.012	0.012	0.036
C34	0.000	0.010	0.013	0.032	0.050	0.007	0.003	0.000	0.006	0.015	0.024	0.055	0.010	0.023	0.000
C35	0.000	0.003	0.000	0.006	0.002	0.005	0.003	0.000	0.009	0.003	0.000	0.008	0.054	0.004	0.036
C36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.017	0.000	0.000
C37	0.000	0.010	0.000	0.000	0.003	0.000	0.004	0.019	0.013	0.007	0.000	0.003	0.006	0.000	0.000
C38	0.000	0.003	0.002	0.004	0.007	0.014	0.011	0.004	0.006	0.015	0.049	0.003	0.012	0.012	0.007
C39	0.000	0.000	0.000	0.000	0.001	0.005	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.007

Table 3 continued

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C40	0.000	0.013	0.005	0.000	0.003	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.010	0.000	0.000
C42	0.000	0.000	0.003	0.000	0.004	0.055	0.012	0.000	0.009	0.003	0.000	0.000	0.000	0.023	0.000
C43	0.000	0.020	0.002	0.002	0.005	0.019	0.007	0.000	0.005	0.004	0.049	0.000	0.000	0.008	0.000
C44	0.000	0.000	0.002	0.002	0.001	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000
C31		C32	C33	C34	C35	C36	C37	C38	C39	C40	C42	C43	C44		
C01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C03	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C04	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C06	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C07	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C09	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.003	0.000
C10	0.065	0.000	0.007	0.016	0.001	0.000	0.014	0.005	0.000	0.000	0.022	0.004	0.003	0.003	0.000
C11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C13	0.000	0.000	0.000	0.000	0.001	0.000	0.016	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
C15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.000	0.000
C16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.012	0.000	0.000
C18	0.002	0.026	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.014
C19	0.000	0.013	0.001	0.005	0.000	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000
C20	0.007	0.013	0.001	0.014	0.001	0.000	0.005	0.004	0.009	0.009	0.012	0.001	0.012	0.000	0.000
C21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.019	0.018	0.007
C22	0.003	0.000	0.001	0.003	0.000	0.000	0.005	0.003	0.013	0.013	0.000	0.005	0.005	0.015	0.007
C23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3 continued

	C31	C32	C33	C34	C35	C36	C37	C38	C39	C40	C42	C43	C44
C24	0.000	0.000	0.004	0.001	0.001	0.002	0.003	0.001	0.022	0.002	0.033	0.003	0.048
C25	0.002	0.000	0.000	0.005	0.000	0.000	0.007	0.005	0.000	0.002	0.004	0.006	0.000
C26	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.015	0.007
C27	0.002	0.051	0.001	0.012	0.001	0.000	0.001	0.000	0.000	0.007	0.005	0.000	0.007
C28	0.000	0.051	0.025	0.017	0.043	0.054	0.015	0.013	0.022	0.039	0.007	0.003	0.021
C29	0.000	0.000	0.004	0.002	0.001	0.000	0.002	0.001	0.000	0.002	0.002	0.000	0.000
C30	0.002	0.013	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.002	0.002	0.000	0.000
C31	0.888	0.000	0.001	0.002	0.000	0.000	0.000	0.002	0.004	0.002	0.016	0.003	0.000
C32	0.000	0.744	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000
C33	0.000	0.013	0.850	0.001	0.007	0.008	0.005	0.011	0.058	0.005	0.014	0.027	0.021
C34	0.007	0.013	0.005	0.875	0.003	0.002	0.003	0.011	0.009	0.064	0.000	0.000	0.000
C35	0.009	0.000	0.021	0.010	0.918	0.023	0.005	0.008	0.022	0.022	0.007	0.006	0.007
C36	0.000	0.000	0.010	0.002	0.011	0.902	0.001	0.001	0.004	0.027	0.000	0.000	0.007
C37	0.003	0.000	0.006	0.002	0.002	0.000	0.888	0.008	0.009	0.005	0.007	0.003	0.062
C38	0.007	0.000	0.026	0.016	0.004	0.002	0.019	0.867	0.119	0.039	0.022	0.021	0.007
C39	0.000	0.000	0.017	0.002	0.001	0.001	0.000	0.011	0.681	0.002	0.001	0.003	0.007
C40	0.000	0.038	0.001	0.009	0.003	0.005	0.001	0.008	0.009	0.731	0.000	0.003	0.000
C42	0.005	0.013	0.014	0.002	0.001	0.001	0.000	0.008	0.013	0.000	0.834	0.015	0.021
C43	0.000	0.013	0.002	0.000	0.000	0.000	0.000	0.003	0.004	0.000	0.014	0.825	0.007
C44	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.001	0.000	0.002	0.000	0.003	0.752

Table 4 Limited priority matrix of technological sectors in Korean national R&D (2008–2011)

	C01	C03	C04	C06	C07	C09	C10	C11	C12	C13	C14	C15
C01	0.007	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006
C03	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
C04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C07	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C09	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
C10	0.132	0.132	0.131	0.131	0.131	0.132	0.132	0.133	0.131	0.132	0.132	0.132
C11	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C13	0.116	0.111	0.110	0.110	0.110	0.112	0.111	0.116	0.110	0.115	0.112	0.111
C14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C15	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
C16	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C17	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
C18	0.009	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
C19	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
C20	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
C21	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
C22	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
C23	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
C24	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
C25	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
C26	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
C27	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
C28	0.105	0.106	0.107	0.106	0.107	0.106	0.106	0.104	0.106	0.105	0.106	0.106
C29	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008

Table 4 continued

	C01	C03	C04	C06	C07	C09	C10	C11	C12	C13	C14	C15
C30	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
C31	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
C32	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C33	0.037	0.038	0.038	0.038	0.038	0.038	0.038	0.037	0.038	0.037	0.038	0.038
C34	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
C35	0.128	0.131	0.131	0.131	0.132	0.130	0.131	0.128	0.131	0.129	0.130	0.131
C36	0.043	0.044	0.044	0.044	0.044	0.044	0.044	0.043	0.044	0.043	0.044	0.044
C37	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
C38	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
C39	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
C40	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
C42	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
C43	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
C44	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29
C01	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
C03	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
C04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C07	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C09	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
C10	0.132	0.131	0.131	0.131	0.131	0.131	0.131	0.132	0.131	0.131	0.131	0.131	0.131	0.131
C11	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C13	0.111	0.110	0.110	0.110	0.110	0.110	0.111	0.114	0.110	0.111	0.110	0.109	0.109	0.110

Table 4 continued

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29
C14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C15	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
C16	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C17	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
C18	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
C19	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
C20	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
C21	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
C22	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
C23	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
C24	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
C25	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
C26	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
C27	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
C28	0.106	0.107	0.107	0.107	0.107	0.107	0.106	0.105	0.107	0.106	0.107	0.107	0.107	0.107
C29	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
C30	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
C31	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
C32	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C33	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.037	0.038	0.038	0.038	0.038	0.038	0.038
C34	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
C35	0.131	0.131	0.131	0.131	0.131	0.132	0.131	0.129	0.132	0.131	0.131	0.132	0.133	0.132
C36	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.043	0.044	0.044	0.044	0.044	0.045	0.044
C37	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
C38	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
C39	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007

Table 4 continued

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29
C40	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
C42	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
C43	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
C44	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
C30	C31	C32	C33	C34	C35	C36	C37	C38	C39	C40	C42	C43	C44	
C01	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	
C03	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
C04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
C06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
C07	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
C09	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	
C10	0.131	0.131	0.131	0.131	0.131	0.130	0.130	0.131	0.131	0.131	0.131	0.131	0.131	
C11	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
C12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
C13	0.109	0.110	0.109	0.109	0.110	0.108	0.108	0.111	0.111	0.110	0.109	0.110	0.110	
C14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
C15	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
C16	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
C17	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	
C18	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	
C19	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	
C20	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	
C21	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
C22	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	
C23	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	

Table 4 continued

	C30	C31	C32	C33	C34	C35	C36	C37	C38	C39	C40	C42	C43	C44
C24	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
C25	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
C26	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
C27	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
C28	0.107	0.106	0.107	0.107	0.107	0.108	0.108	0.106	0.106	0.107	0.107	0.107	0.107	0.107
C29	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
C30	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
C31	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
C32	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
C33	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
C34	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
C35	0.132	0.131	0.132	0.132	0.132	0.133	0.133	0.131	0.131	0.132	0.132	0.132	0.132	0.132
C36	0.045	0.044	0.044	0.044	0.044	0.045	0.045	0.044	0.044	0.044	0.044	0.044	0.044	0.044
C37	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
C38	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
C39	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
C40	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
C42	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
C43	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
C44	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002

Table 5 The coreness and rank of technology sectors

Technology sector	Coreness	Rank	Technology sector	Coreness	Rank
C01	0.0063	24	C24	0.0244	11
C03	0.0054	26	C25	0.0200	14
C04	0.0004	39	C26	0.0026	29
C06	0.0007	36	C27	0.0104	18
C07	0.0007	37	C28	0.1065	4
C09	0.0061	25	C29	0.0077	21
C10	0.1313	1	C30	0.0025	30
C11	0.0011	34	C31	0.0211	12
C12	0.0001	40	C32	0.0010	35
C13	0.1106	3	C33	0.0377	8
C14	0.0004	38	C34	0.0663	6
C15	0.0024	31	C35	0.1312	2
C16	0.0015	33	C36	0.0441	7
C17	0.0064	23	C37	0.0329	10
C18	0.0095	20	C38	0.0809	5
C19	0.0124	17	C39	0.0066	22
C20	0.0350	9	C40	0.0138	16
C21	0.0053	27	C42	0.0201	13
C22	0.0192	15	C43	0.0098	19
C23	0.0036	28	C44	0.0020	32

limit matrix by multiplying priority matrix. The priority matrix for technology sectors in Korean national R&D was nearly settled down at W^{141} (Table 4), thus we could identify the coreness for each of 40 technology sectors (Table 5).

Technological intermediarity analysis

To identify the intermediarity of technology sectors in Korean national R&D, we used the concept of betweenness centrality to the TKF matrix among technology sectors (Table 2). In the TKF network, the node with high betweenness centrality plays an important role in the diffusion of technological knowledge as an intermediary. Therefore, this measure is appropriate to be used as a proxy for intermediarity of technology sectors.

The ANP-based coreness described above uses the dependence and self-influence of technology sectors, while intermediarity based on betweenness centrality uses only the relationships among different technology sectors. The intermediarity of a directed network is defined as follows:

$$g(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

where σ_{st} is the total number of shortest paths from node s to node t , and $\sigma_{st}(v)$ is the number of those paths that pass through node v .

After eliminating self-influence, this step identified a directed network for node betweenness centrality analysis (Fig. 5) and measured the intermediarity of each of 43

technology sectors (Table 6). The size of each node indicates the degree of betweenness centrality of the node in the network.

Knowledge spillover portfolio map construction

Building on the analysis of technological coreness and intermediarity, we constructed a visual map, called a knowledge spillover portfolio map, which allows policy makers or decision makers to synthetically consider both coreness and intermediarity. In the map, each technology sector is 1 of the 4 dimensions (Table 7). If a technology sector has high coreness and high intermediarity, then we can regard that the sector has a strong possibility of being an active technology sector with high technological impact and various potential technological applications to other technology sectors. A technology sector with low coreness and high intermediarity suggests that the sector is not currently now actively researched but may be a possibility of being a promising technology area with high

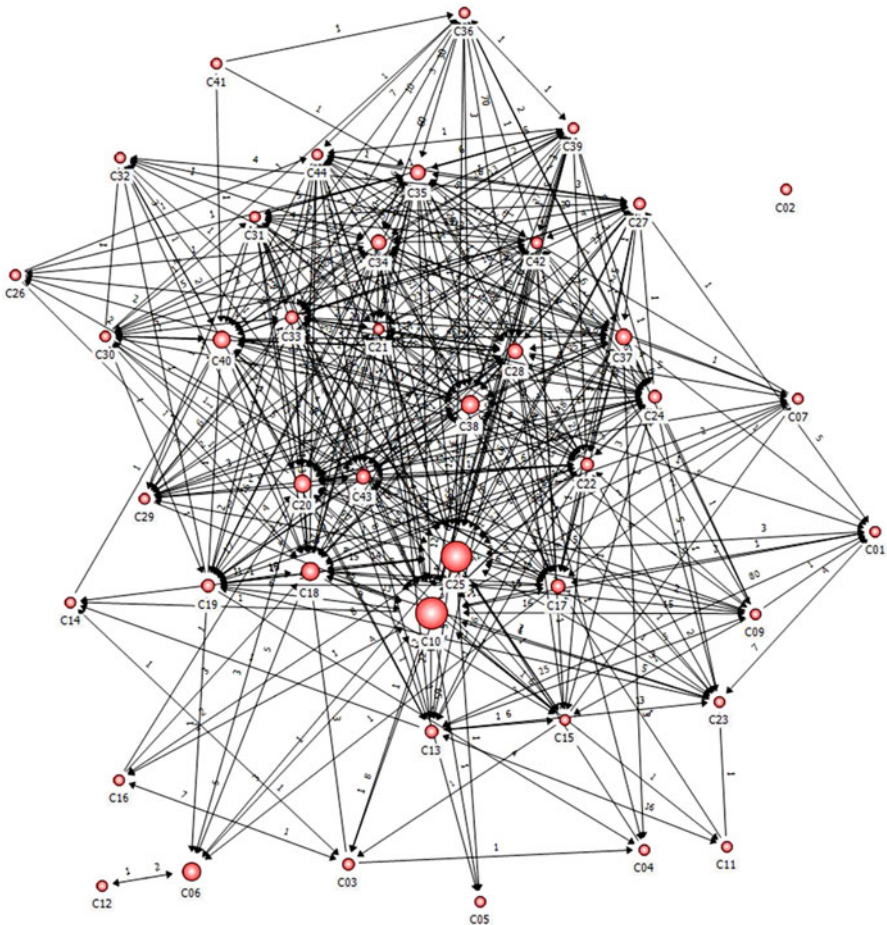


Fig. 5 A network model for betweenness analysis of Korean national R&D

Table 6 The intermediarity and rank of technology sectors

Technology sector	Intermediarity	Rank	Technology sector	Intermediarity	Rank
C01	0.0008	31	C24	0.0117	18
C02	0.0000	40	C25	0.1105	2
C03	0.0076	21	C26	0.0001	38
C04	0.0003	36	C27	0.0092	20
C05	0.0000	40	C28	0.0284	9
C06	0.0453	4	C29	0.0010	30
C07	0.0004	35	C30	0.0022	29
C09	0.0007	32	C31	0.0032	26
C10	0.1158	1	C32	0.0007	33
C11	0.0001	39	C33	0.0118	17
C12	0.0000	40	C34	0.0255	11
C13	0.0155	14	C35	0.0283	10
C14	0.0005	34	C36	0.0045	22
C15	0.0032	24	C37	0.0294	8
C16	0.0002	37	C38	0.0454	3
C17	0.0177	13	C39	0.0026	28
C18	0.0427	5	C40	0.0358	6
C19	0.0148	16	C41	0.0000	40
C20	0.0352	7	C42	0.0114	19
C21	0.0032	25	C43	0.0197	12
C22	0.0149	15	C44	0.0029	27
C23	0.0041	23	–	–	–

applicability to other adjacent technology sectors. Likewise, we can formulate technological implications about the technology sectors located in the map (Table 7).

This step visualizes a technology spillover portfolio map for Korean national R&D by incorporating coreness and intermediarity of technology sectors (Fig. 6); the vertical line is the average coreness and the horizontal line is the average intermediarity. Finally, we found that technology sectors including C10, C20, C28, C34, C35, C37, and C38 had high coreness and high intermediarity (Area A), technology sectors including C13, C24, C33, and C36 had high coreness and low intermediarity (Area B), technology sectors including C06, C17, C18, C25, and C40 had high intermediarity but low coreness (Area C), and the other sectors had low coreness and intermediarity (Area D). The analysis results of Korean national R&D was as follows:

- Technology sectors in Area A, which have high coreness and intermediarity, can be considered to be the basic science or technology sectors which should be focused on as a top priority by Korean national R&D. First, C10 (Basic chemical) was assessed as the most promising technology sector. Since the nature of basic science involves a high risk of R&D failure and requires many resources, a huge infrastructure, and a long time to understand the results. Therefore, research by corporations or private research institutes is difficult. Thus, Korean national R&D should consistently invest in C10 to improve the ability of Korea to compete technologically. Second, technologies in C38 (Measuring instruments) are mainly methods and apparatuses to measure electrical

Table 7 Dimensions and technological meanings in the knowledge spillover portfolio map

	Low intermediarity	High intermediarity
High coreness	<ul style="list-style-type: none"> • Area with high technological impact but low applicability potential to other technology sectors • Main technology sector that has been actively researched mainly to improve technological coreness, but research for interdisciplinary or application-related purposes has been insufficient 	<ul style="list-style-type: none"> • Area with high technological impact and various applications to other technology sectors • Main technology sector that has been actively researched to improve both technological coreness and intermediarity
Low coreness	<ul style="list-style-type: none"> • Area with low technological impact and low applicability to other technology sectors • Sector that is unpromising or inappropriate as national R&D project so has rarely been researched by national supports • Sector that presents very low performance in national supported research 	<ul style="list-style-type: none"> • Area with low technological impact but high applicability potential to other technology sectors • Sector that has not been actively researched but is promising

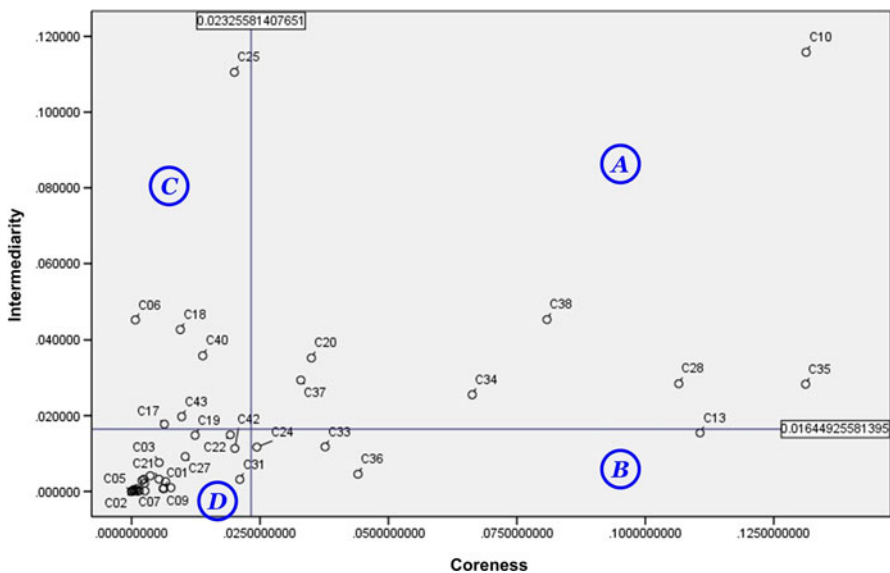


Fig. 6 Knowledge spillover portfolio map for Korean national R&D

quantities, mechanical properties of material, or physical or chemical properties, which have various applications. However, although C38 had higher coreness and intermediarity than other sectors, its intermediarity is relatively low compared to its coreness. Thus, further national R&D programs for C38 should improve the intermediarity of the sector. Third, C35 (Signal transmission, telecommunications), C28 (Office machinery and computers), and C34 (Electronic components) are the basic technology sectors for IT-related technologies and products in which Korea is already competitive globally as one of the first-movers. Specifically, these sectors contain data communication methods

and systems (C35) and display- and semiconductor-related technologies (C28 and C34). Considering the relative size and importance of the IT industry in Korea, it is no doubt that consistent support of these sectors is necessary. However, the absolute intermediarity of these sectors is not much higher than other sectors, thus the efforts to increase the intermediarity of the sectors are required. At the same time, however, the biased allocation of R&D budgets to these sectors should be avoided.

- Technology sectors included in Area B, which have high coreness but low intermediarity, can be considered to be the sectors that are technologically important, but may not have properly conducted the interdisciplinary research with other sectors to promote technological spillover and convergence or may contain technologies which are difficult to apply to other sectors due to their technological characteristics. First, C13 (Pharmaceuticals) contains chemical and biological technologies for pharmaceutical and medical substances. This sector, as one of basic sciences, has great technological impact on other industries and its own sector, but involves a high risk of R&D failures and a large financial investment to develop and test new medical substances. Until recently, Korean national R&D programs have not paid sufficient attention to this sector, thus the Korean pharmaceutical industry has not enough technological capabilities to compete globally. Several large foreign pharmaceutical companies have exclusive core technologies. However, considering that issues on human health have become increasingly important, this sector is worthwhile for intensive investment to build it as one of the future core technology areas for Korea. Second, C36 (Television and radio receivers, audiovisual electronics) mainly contains digital signal processing technologies and apparatuses to transmit or receive signal data. Considering the characteristics of technologies in C36, the technologies can directly impact to some industries, such as broadcasting and telecommunications, as the fundamental technologies, and thus the coreness of the sector was relatively high compared to other sectors. The intermediarity, however, was quite low. Therefore, in national R&D planning for C36, projects that focus on increasing the intermediarity should be selected to improve the weakness of the sector and to maximize the benefits and effects of national R&D.
- Technology sectors in Area C, which have high intermediarity but low coreness, can be considered to be the sectors that have high efficiency of the investments, but should be focused on improving the technological coreness. First, C25 (Special purpose machinery) includes technologies for the manufacture of various machineries, such as for metallurgy, mining or quarrying, construction, food and textile, or apparel. The intermediarity of C25 was evaluated to be very high, because although the technologies in the sectors do not have large impacts on other sectors, they play a significant role to catalyze the knowledge spillover from the overall industry perspective. Improving the coreness of C25 could be the effective R&D strategy at national level due to its characteristics as technological knowledge intermediary. Therefore, a strategic direction of R&D projects for C25 should focus on both maintaining its high intermediarity and increasing the coreness. Second, C40 (Optical instruments) is mainly about the optical elements or apparatus, such as lenses, filters and prisms, which can be applied to various products in different technology sectors as the important components. Technologies in C40 are based on various basic sciences and technologies from outside of the sector, and thus C40 functions as a bridge between the sectors and has relatively high intermediarity than other sectors. However, the Korean optical industry has insufficient technical capabilities and rarely developed the critical technologies, which can have great impacts on both its own sector and other sectors.

Accordingly, the coreness of C40 is relatively low. Therefore, further R&D projects for C40 need to be focused on developing the core technologies to improve the coreness of the sectors.

- Technology sectors in Area D, which have low coreness and intermediarity, can be interpreted in two categories. One is the sectors that are unpromising or inappropriate as national R&D project and thus have rarely been researched by national support. Most of sectors in Area D can be included in this category. C01 (Food, beverages), C02 (Tobacco products), C03 (Textiles), C04 (Wearing apparel), C05 (Leather articles), C07 (Paper), C09 (Petroleum products, nuclear fuel), C11 (Pesticides & agro-chemical products), C12 (Paints, varnishes), C14 (Soaps, detergents, toilet preparations), C15 (Other chemicals), C16 (Man-made fibres), C23 (Agricultural and forestry machinery), C39 (Industrial process control equipment), C41 (Watches, clocks) and C44 (Furniture, consumer goods) are inappropriate as national supported research due to their industrial characteristics. C22 (Non-specific purpose machinery), C27 (Domestic appliances), C30 (Electric distribution, control, wire, cable), C32 (Lighting equipment) and C42 (Motor vehicles) are considered as the unpromising sectors because they are technologically matured sectors (C30, C42) or application-oriented sectors having low technological impacts, where are suitable for corporate-driven R&D projects (C22, C27, C32). The other is the sectors that are recognized as technologically promising but have generated poor research performance and quality from national R&D projects, and C19 (Basic metals), C21 (Energy machinery), C29 (Electric motors, generator, transformers) and C31 (Accumulators, battery) are involved in this category. If further national R&D programs support the sectors to develop as new growth engine industries, specific R&D directions for the sectors should be planned to primarily improve the coreness of the sectors. Although C26 (Weapons and ammunition) is mapped on Area D and appropriate as national R&D project, it may be difficult to recognize the research outputs or results of C26 through patent analysis: detailed information on this sector may be unreleased to the public and treated as a national secret.

Discussion

The analysis described here is based on TKFs from patent co-classification information. The patent co-classification based approach has advantages over a patent citation based approach. A citation-based approach is inappropriate to analyze recent patents, which have not or rarely been cited by other patents and to analyze patent databases that do not require patent citation information. A co-classification based approach can resolve these limitations. Because we analyzed recently granted Korean national R&D patents from 2008 to 2011, the patent co-classification approach fit the purpose.

To assess the coreness and intermediarity of each technology sector, ANP and SNA were used. First, ANP, which considers dependence and self-influence of a technology sector, can evaluate the coreness of each sector from a TKF network. Because of the methodological characteristics of ANP that each node, i.e., technology sector, on network has to have interaction flows with other nodes, the case of Korean national R&D has some omitted sectors (C2, C5, and C41) that could not be considered by ANP. These omitted sectors, however, have been recognized as inadequate for national support according to their technological characteristics (tobacco products, leather articles, and watches and

clocks), thus previous Korean national R&D programs have provided little or no support. Therefore, omitting these sectors did not negatively influence the results of the coreness analysis. Second, betweenness centrality analysis was used to assess the intermediarity of technology sectors. Although the extent of knowledge out-flows of a technology sector, i.e., degree centrality, can indicate the technological influence of a specific sector from the specific sectoral perspective, the diffusion of knowledge throughout the overall industry can be determined by its relative position as an intermediary on the network. If, without considering the overall industrial perspective, evaluation of the sectors, which have relatively small knowledge out-flows but are at the critical positions for knowledge diffusion, may not be objectively implemented. Using betweenness centrality analysis, technological position as a knowledge intermediary can be a criterion for evaluating the intermediarity of technology sectors. Thus, we used betweenness centrality instead of degree centrality to measure intermediarity.

For the effective analysis, we classified all industrial sectors into four categories on the knowledge spillover portfolio map. However, some sectors that fall around the borderlines may be difficult to be clearly classified into a certain category. For example, the intermediarity of C13 (0.0155) and C17 (0.0177) are quite similar, but C13 was evaluated as low intermediarity and C17 was evaluated as high intermediarity. Therefore, when planning for R&D project for an industrial sector, it should be considered not only which category (or dimension) the sector is involved in, but also specific coordinate of the sector on the knowledge spillover portfolio map.

The results from the case study can help decision making for project selection and budget allocation in national R&D planning. In particular, this study not only identified technology sectors that should be prioritized and intensively supported at a national level, but also provided the significant knowledge to developing specific strategic directions for further R&D projects by evaluating the coreness and intermediarity of the sectors and mapping them on a knowledge spillover portfolio map. However, although the analysis results are important for Korean national R&D planning, relying solely on the results for decision-making of national R&D project selection and budget allocation should be avoided to make R&D plans more reasonable and feasible. Other factors from the environmental and strategic perspectives also need to be considered for the optimal R&D decisions; for instance, nature of technology and network effect in market can also be considered as the indicators for national R&D policy (Dolfsma and Seo 2013).

Conclusion and further research topics

This study proposed a framework to evaluate the coreness and intermediarity of technology sectors for Korean national R&D planning. For the purpose, the proposed method used patent co-classification to generate a knowledge flow network that can overcome the limitations of a citation-based approach. Coreness of the sectors was evaluated using ANP, which can consider dependence among the sectors, and intermediarity was evaluated using betweenness centrality analysis, which can reduce the overestimation of intermediarity due to the large number of patents in a sector. The framework provides a visual map, called a knowledge spillover portfolio map, which allows policy makers or decision makers to synthetically consider both coreness and intermediarity. Therefore, the framework provides critical information for project selection and budget allocation and also for developing a specific strategic direction in Korean national R&D planning.

However, in spite of the advantages and useful contributions of the framework, the research has some limitations and further research is needed. First, the present study used only patents granted from 2008 to 2011. Further research can extend the scope of the patent set to the latest patent applications, even though they have not been granted, to identify the latest trends in Korean national R&D. Unlike a citation-based approach, a co-classification-based approach can use any patent applications as data for a knowledge flow network. Second, a comparative analysis for national R&D trends between Korea and other countries can provide meaningful knowledge regarding the distinct characteristics and tendencies of Korean national R&D. Third, the present research only analyzed recent Korean national R&D trends. By using a wider-range of patents, such as patents in the last 10 years, and analyzing them by year, trends in Korean national R&D over time can be identified. Finally, the research classified the technology into 44 technology sectors by ISIC-based sector classification. Although the classification is appropriate to identify the national R&D trends from an industrial perspective, it is inappropriate to analyze national R&D trends within specific technology area. Thus, to identify the detailed trends of a technology area in a further research topic, the classification of the technology sectors needs to be more specific.

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Appendix

See Appendix Table 8.

Table 8 IPC-ISIC concordance table

No.	Field name	IPC classes
1	Food, beverages	A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, A23P, C12C, C12F, C12G, C12H, C12J, C13F, C13J, C13K
2	Tobacco products	A24B, A24D, A24F
3	Textiles	D04D, D04G, D04H, D06C, D06J, D06M, D06N, D06P, D06Q
4	Wearing apparel	A41B, A41C, A41D, A41F
5	Leather articles	A43B, A43C, B68B, B68C
6	Wood products	B27D, B27H, B27M, B27N, E04G
7	Paper	B41M, B42D, B42F, B44F, D21C, D21H, D21J
8	Publishing, printing	
9	Petroleum products, nuclear fuel	C10G, C10L, G01V
10	Basic chemical	B01J, B09B, B09C, B29B, C01B, C01C, C01D, C01F, C01G, C02F, C05B, C05C, C05D, C05F, C05G, C07B, C07C, C07F, C07G, C08B, C08C, C08F, C08G, C08J, C08K, C08L, C09B, C09C, C09D, C09K, C10B, C10C, C10H, C10J, C10K, C12S, C25B, F17C, F17D, F25J, G21F
11	Pesticides & agro-chemical products.	A01N
12	Paints, varnishes	B27K
13	Pharmaceuticals	A61K, A61P, C07D, C07H, C07J, C07K, C12N, C12P, C12Q

Table 8 continued

No.	Field name	IPC classes
14	Soaps, detergents, toilet preparations	C09F, C11D, D06L
15	Other chemicals	A62D, C06B, C06C, C06D, C08H, C09G, C09H, C09J, C10M, C11B, C11C, C14C, C23F, C23G, D01C, F42B, F42D, G03C
16	Man-made fibres	D01F
17	Rubber and plastics products	A45C, B29C, B29D, B60C, B65D, B67D, E02B, F16L, H02G
18	Non-metallic mineral products	B24D, B28B, B28C, B32B, C03B, C03C, C04B, E04B, E04C, E04D, E04F, G21B
19	Basic metals	B21C, B21G, B22D, C21B, C21C, C21D, C22B, C22C, C22F, C25C, C25F, C30B, D07B, E03F, E04H, F27D, H01B
20	Fabricated metal products	A01L, A44B, A47H, A47K, B21K, B21L, B22F, B25B, B25C, B25F, B25G, B25H, B26B, B27G, B44C, B65F, B82B, C23D, C25D, E01D, E01F, E02C, E03B, E03C, E03D, E05B, E05C, E05D, E05F, E05G, E06B, F01K, F15D, F16B, F16P, F16S, F16T, F17B, F22B, F22G, F24J, G21H
21	Energy machinery	B23F, F01B, F01C, F01D, F03B, F03C, F03D, F03G, F04B, F04C, F04D, F15B, F16C, F16D, F16F, F16H, F16K, F16M, F23R
22	Non-specific purpose machinery	A62C, B01D, B04C, B05B, B61B, B65G, B66B, B66C, B66D, B66F, C10F, C12L, F16G, F22D, F23B, F23C, F23D, F23G, F23H, F23J, F23K, F23L, F23M, F24F, F24H, F25B, F27B, F28B, F28C, F28D, F28F, F28G, G01G, H05F
23	Agricultural and forestry machinery	A01B, A01C, A01D, A01F, A01G, A01J, A01K, A01M, B27L
24	Machine-tools	B21D, B21F, B21H, B21J, B23B, B23C, B23D, B23G, B23H, B23K, B23P, B23Q, B24B, B24C, B25D, B25J, B26F, B27B, B27C, B27F, B27J, B28D, B30B, E21C
25	Special purpose machinery	A21C, A22B, A22C, A23N, A24C, A41H, A42C, A43D, B01F, B02B, B02C, B03B, B03C, B03D, B05C, B05D, B06B, B07B, B07C, B08B, B21B, B22C, B26D, B31B, B31C, B31D, B31F, B41B, B41C, B41D, B41F, B41G, B41L, B41N, B42B, B42C, B44B, B65B, B65C, B65H, B67B, B67C, B68F, C13C, C13D, C13G, C13H, C14B, C23C, D01B, D01D, D01G, D01H, D02G, D02H, D02J, D03C, D03D, D03J, D04B, D04C, D05B, D05C, D06B, D06G, D06H, D21B, D21D, D21F, D21G, E01C, E02D, E02F, E21B, E21D, E21F, F04F, F16N, F26B, H05H
26	Weapons and ammunition	B63G, F41A, F41B, F41C, F41F, F41G, F41H, F41J, F42C, G21J
27	Domestic appliances	A21B, A45D, A47G, A47J, A47L, B01B, D06F, E06C, F23N, F24B, F24C, F24D, F25C, F25D, H05B
28	Office machinery and computers	B41J, B41K, B43M, G02F, G03G, G05F, G06C, G06D, G06E, G06F, G06G, G06J, G06K, G06M, G06N, G06T, G07B, G07C, G07D, G07F, G07G, G09D, G09G, G10L, G11B, H03K, H03L
29	Electric motors, generators, transformers	H02K, H02N, H02P
30	Electric distribution, control, wire, cable	H01H, H01R, H02B
31	Accumulators, battery	H01M
32	Lighting equipment	F21H, F21K, F21L, F21M, F21S, F21V, H01K
33	Other electrical equipment	B60M, B61L, F21P, F21Q, G08B, G08G, G10K, G21C, G21D, H01T, H02H, H02M, H05C

Table 8 continued

No.	Field name	IPC classes
34	Electronic components	B81B, B81C, G11C, H01C, H01F, H01G, H01J, H01L
35	Signal transmission, telecommunications	G09B, G09C, H01P, H01Q, H01S, H02J, H03B, H03C, H03D, H03F, H03G, H03H, H03M, H04B, H04J, H04K, H04L, H04M, H04Q, H05K
36	Television and radio receivers, audiovisual electronics	G03H, H03J, H04H, H04N, H04R, H04S
37	Medical equipment	A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, A62B, B01L, B04B, C12M, G01T, G21G, G21K, H05G
38	Measuring instruments	F15C, G01B, G01C, G01D, G01F, G01H, G01J, G01M, G01N, G01R, G01S, G01W, G12B
39	Industrial process control equipment	G01K, G01L, G05B, G08C
40	Optical instruments	G02B, G02C, G03B, G03D, G03F, G09F
41	Watches, clocks	G04B, G04C, G04D, G04F, G04G
42	Motor vehicles	B60B, B60D, B60G, B60H, B60J, B60K, B60L, B60N, B60P, B60Q, B60R, B60S, B60T, B62D, E01H, F01L, F01M, F01N, F01P, F02B, F02D, F02F, F02G, F02M, F02N, F02P, F16J, G01P, G05D, G05G
43	Other transport equipment	B60F, B60V, B61C, B61D, B61F, B61G, B61H, B61J, B61K, B62C, B62H, B62J, B62K, B62L, B62M, B63B, B63C, B63H, B63J, B64B, B64C, B64D, B64F, B64G, E01B, F02C, F02K, F03H
44	Furniture, consumer goods	A41G, A42B, A44C, A45B, A45F, A46B, A46D, A47B, A47C, A47D, A47F, A63B, A63C, A63D, A63F, A63G, A63H, A63J, A63K, B43K, B43L, B44D, B62B, B68G, C06F, F23Q, G10B, G10C, G10D, G10F, G10G, G10H

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