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Article

A Study on Diffusion Pattern of Technology Convergence: Patent Analysis for Korea

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Abstract: Technology convergence indicates that technologies of different application areas are converted into a new and common unity of technology. Its range spans from inter-field, whereby technologies are converged between heterogeneous fields in homogeneous sector, to a wider inter-sector, whereby technologies belong to heterogeneous technology sector are converged. This paper determined the definition of technology convergence from previous literature and classified patents into technology category depending on patent information. Furthermore, we empirically measure technology convergence degree based on co-classification analysis and estimate its diffusion trend at the entire technology domain level by using overall 1,476,967 of patents filed to the KIPO (Korean Intellectual Property Office) from 1998 to 2010. As a result, potential size and growth rate of technology convergence are varied by both technology and type of technology convergence, *i.e.*, inter-field and inter-sector technology convergence. Diffusion pattern of inter-sector technology convergence appears as the more various form than that of inter-field technology convergence. In a relationship between potential size and growth rate of technology convergence, growth rate of technology convergence is in inverse proportion to potential size of technology convergence in general. That is, the faster the growth rate of technology convergence, the smaller the potential size of technology convergence. In addition, this paper found that technology convergence of the instrument and chemistry sector is actively progressing in both inter-field and inter-sector convergence, while the technologies related to Information and Communication Technology (ICT) in electrical engineering sector have relatively mature progress of technology convergence, especially in inter-sector technology convergence.

Keywords: technology convergence; diffusion pattern; patent data; sustainability; co-classification analysis

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1. Introduction

Technology convergence as a means of ensuring the future innovative technology is regarded as not a theoretical terminology, but an important strategy inevitably faced in the practical research and development fields. This technology convergence has been influencing significantly to enhance the competitiveness of R&D entities and reorganize the industrial structure in practice [1].

From a business viewpoint, technology convergence may improve a path dependency to serve as a stumbling block to firm's innovative activities and provide a strategy to secure competitive advantages. In addition, it does not only create opportunities to develop a new technology and knowledge, but can also be an important driver to change firms' orientation towards new market [2,3].

From an industry viewpoint, technology convergence can play a role to induce industrial convergence by integrating a complementary knowledge pool to promote technological and industrial clusters [4,5]. In other words, technology convergence may foster the cooperation between firms belonging to heterogeneous industry and contribute to reorganizing industrial structure.

For these reasons, it is increasingly important to occupy converging technologies in advance [6–8]. Many countries, therefore, have established the various support programs to promote technology convergence. The United States at the level of federal government firstly demonstrated technology convergence based on information technology (IT) through the Networking and Information Technology Research Development program (NITRD) in early 1990. After that, the National Science Foundation (NSF) and Department of Commerce (DC) have led a steady R&D investment through National Nanotechnology Initiative (NNI) program, NITRD program, and so on. On the other hand, European Union (EU) proposed a comprehensive concept for technology convergence which contains a social science to strengthen the competitiveness and sets up for the future society of Europe beyond a simple technological change. The prospect for technology convergence has been reflected on the sixth and seventh "Framework Programme" of EU and has been promoting R&D activity for technology convergence. Korea established "Basic Principal for Development of National Technology convergence" in 2006 and has tried to support R&D projects. Since 2012, he has been enforcing a national competence of science and technology innovation, developing structure of the primary industry and fostering a creative economy by establishing a principal plan for the industrial convergence and a strategy for IT convergence diffusion.

Along with these scientific and social attentions to technology convergence, academic research in technology convergence has shown a fast growth since early 2000s. They have emphasized that technology convergence enables a firm to lead and dominate technological innovation in next-generation [6,8–11]. Some empirical studies suggest evidence for technology convergence to emerge gradually over time by evolutionary aspect of convergence [7,12–15]. However, although importance on technology convergence has been constantly emphasized since its initiatives began, its definition and measurement is ambiguous due to a different definition and analysis method by scholar. In addition, there are few empirical studies to investigate technology convergence, and even little substantive empirical evidence exists regarding the overall emergence and diffusion trend of technology convergence. This is fundamentally caused by the ambiguous definition of technology convergence, absence of standardized methodology to measure technology convergence, and lack of appropriate data [10].

Therefore, this paper investigates the definition of technology convergence and an appropriate methodology to measure it from previous literatures. Furthermore, we empirically measure technology convergence degree based on co-classification analysis and estimate its diffusion trend at the entire technology domain level by using patents filed to the KIPO (Korean Intellectual Property Office) from 1998 to 2010 patents.

This paper is novel in offering comprehensive evidence about the diffusion direction of technology convergence compared to the previous literature that has not empirically corroborated. We collected overall 1,476,967 of patent applications from KIPO covering a 13-year period and classified patent into technological category by patent information. This may provide the reliable and generalizable evidence to not only shed light on the landscape of technology convergence but also determine which developmental stage technology convergence is in, and what direction of its diffusion may develop. Through this, this paper may suggest insights of the future trends of technology convergence, which enables policy maker to establish effective and efficient innovation policy reflecting the predictable future trend. Further, this paper may provide insight about furthering industrial convergence for firm as well as help R&D planners to explore opportunities for technology convergence.

The remainder of this paper is as follows. Section 2 briefly determines previous literatures for the definition and the measurement of technology convergence. Section 3 describes the empirical methodology and estimates diffusion pattern of technology convergence. Section 4 reports the results of our analysis and discusses them. Finally, Section 5 offers some concluding remarks and implications of this study.

2. Measurement of Technology Convergence Degree

2.1. Previous Studies to Measure Convergence

The first attempt to define the "Convergence" was done by Nathan Rosenberg in 1960s. Rosenberg pointed out technology convergence in mechanical instrument technology and since then, there were many discussions about its definition. Convergence phenomenon occurs in various fields such as product, service, technology and business, but its definition by scholars is varied [7,16]. However, the nature of convergence is gradually identified by recent in-depth studies, and a consensus among scholars on the definition and classification of convergence is reaching. Despite different definitions by scholar, convergence can be generally explained by the concept that discrete and heterogeneous items converted into unity or uniformity, or distinct technologies, devices, or industries are merged into a unified whole [7,9,16,17]. Some use terminology of convergence mixed with a concept of fusion.

Convergence and fusion have similarity in a concept of mixing the discrete and heterogeneous things. However, there is a differentiate meaning that convergence involves creation of a new thing or value, while fusion is just a combination of things [7].

As shown in Table 1, several scholars have attempted to categorize the identical levels of convergence and measure it in practice [7,14,16]. According to their studies, convergence can be largely classified into the three categories of science convergence, technology convergence and industry convergence. First, science convergence means that different scientific knowledge or disciplines are merged into a new and common unity of knowledge. Second, technology convergence indicates that technologies of different application areas are converted into a new and common unity of technology. Third, industry convergence means that sets of firms in different technology and business model are reorganized into a new and common unity of market/industry [7,17].

Table 1. Previous empirical literatures related to technology convergence.

Level	Data	Methodology	Study
Science	Thesis	Co-word analysis	Callon *et al.* (1986) [18] Palmer (1999) [19]
		Co-citation analysis	Small (1977) [20] Zitt *et al.* (2005) [21] Leydesdorff (2007) [22] Porter and Rafols (2009) [23] Porter *et al.* (2008) [24]
		Co-authorship analysis	Porter *et al.* (2007) [25]
		Co-classification analysis	Noyon and van Raan (1998) [26] Tijssen (1992) [27] Morillo *et al.* (2003) [28] Schummer (2004) [29]
Technology	Patent	IPC co-classification analysis *	Curran and Leker (2011) [7] Geum *et al.* (2012) [30] Jeong (2014) [31] Jeong *et al.*(2015) [17]
		Co-citation analysis	Geum *et al.* (2012) [30]
Industry	Industry information, Patent	SIC-IPC concordance analysis *	Pennings and Puranam (2001) [32] Athreye and Keeble (2000) [6] Fai and Tunzelmann (2001) [33] Curran *et al.* (2010) [34] Karvonen *et al.* (2012) [14] Karvonen and Kassi (2013) [16]
		Input-output analysis	Xing *et al.* (2011) [35]

Note: 1. These categories are referred to [7]. 2. The mark "*" includes the studies using a similar classification instead of SIC or IPC. Source: Jeong *et al.* (2015) [17].

Meanwhile, although it is still an early stage of measuring the convergence degree [10], the next section briefly introduces methodologies to measure convergence based on the previous literatures.

2.1.1. Measurement of the Science Convergence

Empirical studies of science convergence are well-coordinated compare to technology convergence by utilizing the various methodologies and data for a long time. These studies have developed based on bibliometrics, especially an analysis of interdisciplinary similarity, in the late 20th century [36].

A co-word analysis, the technique of comparing the words concurrently appeared on different journals or papers, and a co-citation analysis, the technique of comparing an academic classification for citing and cited papers, are representative analysis methods. In addition, there are a co-authorship that utilizes an affiliated organization and department of co-author and a co-classification that uses multiplex classifications of journals or papers. In recent research, methods to combine different methodologies have been appearing, which compensates the disadvantages while benefits from the advantages of each methodology [37].

2.1.2. Measurement of Technology Convergence

In contrast to science convergence, technology convergence suggests the experimental methodology or performs empirical study by using patent data. Patent is the representative indicator of technology innovation [38]. As a patent analysis is practical method for macroeconomic perspective, previous empirical studies were often conducted by using this method [14]. For example, Curran and Leker (2011) [7] introduced co-classification analysis and identified convergence of IT goods by using US patent data. Geum *et al.* (2012) [30] also analyzed convergence of IT sector by using International Patent Classification (IPC) code.

Previous studies that tried to measure technology convergence generally used co-citation analysis from a patent or co-classification analysis from technological categories of a patent [7,30,31]. According to the following advantages, co-classification analysis is more widely used than co-citation analysis.

First, co-classification analysis has higher reliability in terms of an original information of analysis object than co-citation analysis. In other words, patent citation information is important for technology convergence, but it cannot be the direct indicator for explaining technology properties of the patent. Also, it is difficult to reflect non-cited inherent know-how and technologies. On the other hand, technology classification of patent can be a direct indicator to explain technological area that the patent classified.

Second, co-citation analysis based on classification system of journal may be a probability indicator. In practice the case that information of journal classification does not consist with the published paper's contents is more than 50% [36]. Therefore, patent citation information is not appropriate for use due to high possibilities on distortion [16,39]. However co-classification analysis is possible to accurately identify because a patent has each code of the technology classification.

2.1.3. Measurement of the Industry Convergence

A measurement of the industry convergence is akin to that of technology convergence as an early stage, but various methodologies based on econometrics approaches have been suggested. To estimate industry convergence the early methods often use Standard Industrial Classification (SIC) code linking to IPC code [6,32,33], and then some scholars including Curran *et al.* (2010) [34] and Karvonen *et al.*

(2012) [14] have developed the method more elaborately. Along with this, a method to measure convergence through inter-industry relation by using input-output table is emerged [35].

2.2. Identification of Technology Convergence Degree

In order to measure technology convergence the following three factors need to be considered beforehand.

(1) Selection of measurement: What indicator will be used to measure technologies?
(2) Selection of classification system: What classification system will be used to classify the measured technologies?
(3) Convergence identification method: What methodologies will be used to identify convergence?

As the first considerable factor, patent information officially announced every year describes technology directly, and this reliable characteristic of patent is suitable for analysis related to technological change with advantage that enables to secure long-term time series data.

As the second considerable factor, a reliable classification system provided by international organization has been used to classify technologies. In the case of science convergence, science area is classified by subject category of a journal referring to "Scopus" or "Web of Science". On the other hand, in technology convergence and industry convergence, technology and industry is often classified by IPC system and SIC system, respectively. IPC system established by World Intellectual Property Organization (WIPO) includes the specific articles of current technology trends. However, it has limitations because it does not perfectly describe their technological categories, and in some case a technology classified by IPC may not link to real product and service.

In order to supplement IPC's shortcomings WIPO provides a linkage between IPC codes and technological categories through "IPC-Technology Concordance Table". This table classifies IPC codes into 35 technology fields as shown in Table 2 and further five major sectors including electrical engineering, instrument, chemistry, mechanical engineering, and other fields. In here, sector can be defined as not an industry classification but an upper technology class to aggregate subdivided technology fields. Some empirical studies have followed SIC-IPC linkage analysis based on WIPO's concordance table to analyze industry convergence [14,16]. This paper uses the IPC-Technology Concordance Table published on 2013 by WIPO in order to classify patents into technologies.

Table 2. Technology classification by World Intellectual Property Organization (WIPO) [40].

Sector	Abbreviation	Field
Electrical Engineering	TECH_01	Electrical machinery, Apparatus, Energy
	TECH_02	Audio-Visual Technology
	TECH_03	Telecommunications
	TECH_04	Digital Communication
	TECH_05	Basic Communication Processes
	TECH_06	Computer Technology
	TECH_07	IT Methods for Management
	TECH_08	Semiconductors

Table 2. *Cont.*

Sector	Abbreviation	Field
Instruments	TECH_09	Optics
	TECH_10	Measurement
	TECH_11	Analysis of Biological Materials
	TECH_12	Control
	TECH_13	Medical Technology
Chemistry	TECH_14	Organic Fine Chemistry
	TECH_15	Biotechnology
	TECH_16	Pharmaceuticals
	TECH_17	Macromolecular Chemistry/Polymers
	TECH_18	Food Chemistry
	TECH_19	Basic Materials Chemistry
	TECH_20	Materials/Metallurgy
	TECH_21	Surface Technology/Coating
	TECH_22	Micro-structural and/Nano-technology
	TECH_23	Chemical Engineering
	TECH_24	Environmental Technology
Mechanical Engineering	TECH_25	Handling
	TECH_26	Machine Tools
	TECH_27	Engines/Pumps/Turbines
	TECH_28	Textile/Paper Machines
	TECH_29	Other special Machines
	TECH_30	Thermal Processes and Apparatus
	TECH_31	Mechanical Elements
	TECH_32	Transport
Other fields	TECH_33	Furniture/Games
	TECH_34	Other Consumer Goods
	TECH_35	Civil Engineering

Source: WIPO (2008) [40].

As the third considerable factor, depending on the aforementioned several advantages of co-classification analysis, we use a methodology to identify technology convergence referring to the study of Jeong *et al.* (2015) [17]. In addition this paper presumes that technology convergence is represented by a patent with multiple technology classifications, since such a patent can be regarded as a technology blended knowledge that belongs to heterogeneous technology domains. A method to measure technology convergence based on IPC code is as follows.

As shown in Figure 1 a patent document includes a single or multiple IPC code, each of them can be matched with the WIPO technology classification. For example, patent #1 and #5 cannot be identified as technology convergence because each of them has single IPC code to be subordinate to the field technology. Although patent #2 has multiple IPC codes, it also cannot be identified as technology convergence because its IPC codes are subordinated to the same field, A1. On the other hand, patent #3 can be identified as technology convergence because it belongs to heterogeneous technology fields, A1 and A2 (hereinafter “inter-field technology convergence”). However, patent #3 cannot be identified by sector because the fields, A1 and A2 are subordinated to same sector, A. Patent #4 is also identified as inter-field technology convergence like patent #3, but its technological fields belong to the heterogeneous technological sectors A and B, which can be regarded as "inter-sector technology convergence" further.

That is, this paper defines inter-field technology convergence that technologies are converged between heterogeneous technology fields in homogeneous sector and inter-sector that technologies belong to heterogeneous technology sector converged. For example, if Telecommunications (TECH_03) and Computer technology (TECH_06) in homogeneous sector, electrical engineering sector, are converged, it can be regarded as inter-field technology convergence. Meanwhile, convergence between heterogeneous sectors such as Telecommunications (TECH_03) and Chemical Engineering (TECH_23) indicates inter-sector technology convergence. Inter-sector convergence may be considered as a convergence between more heterogeneous technologies than inter-field convergence.

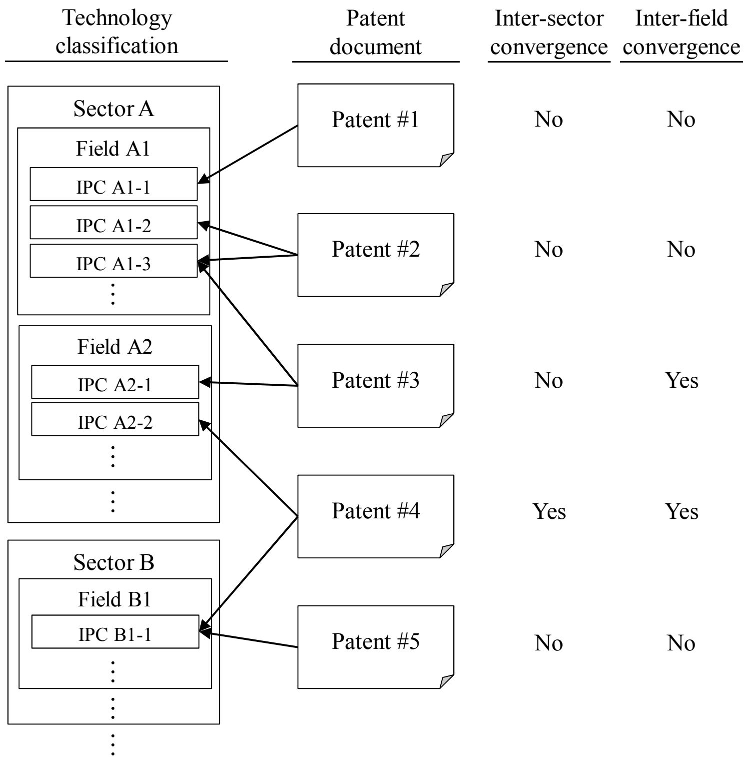


Figure 1. Measurement of technology convergence by using International Patent Classification (IPC) code. Source: Jeong *et al.* (2015) [17].

After identifying technology convergence by WIPO technology classification, this paper defines technology convergence degree as patents identified as technology convergence compared to overall patents in order to estimate diffusion pattern as well as verify trend of technology convergence. We calculate it as the ratio between the number of technology convergence patents divided by the total number of entire patent as shown in Equation (1). This paper assumes that technology convergence degree involving a concept of ratio has phenomenologically cumulative attribute influenced by previous convergence. In practice, we confirmed that technology convergence degree of all technologies has experienced continuous increase during the analysis period. This technology convergence degree is drawn by technology field and sector classified by WIPO.

$$\text{Technology convergence degree} = \frac{\text{The number of technology convergence patents}}{\text{The total number of entire patents}} \quad (1)$$

3. Analysis of Diffusion Pattern of Technology Convergence

3.1. Estimation Model for Diffusion Pattern of Technology Convergence

Since early 20th century various diffusion models have been developed in different fields. The diffusion model is generally used to explain diffusion of products or services in aspect of business management in the initial stage, but it has been widely utilized to social science including anthropology and sociology as well as natural science including biology *etc.*

The diffusion model has largely three development stages: The era of basic models (1960–1970), the era of expanded models (1970–1980), the era of new application (after 1980) [41]. In the era of basic models, the research concentrated on development of mathematical models and after then various applied models were developed vigorously based on “Bass diffusion model”. Since 1980’s, the research has expanded the scope and flexibility of models by improving prior methodologies and further applied diffusion models to new products and services such as HDTV, IP communication services and so on [41].

The whole period of diffusion based on Bass model can be divided into three phases, embryonic phase, growing phase and mature phase. The general form of diffusion curve is “S” shape which cumulative adoptions of new product/service or new technology experience a low growth at embryonic phase through an increasing growth at growing phase to the stagnant growth at mature phase [42].

General diffusion model can be suggested as a following differential equation. Where at any time t, $N(t)$ and $n(t)$ are the cumulative and noncumulative number of adopters respectively, m is the potential number of ultimate adopters. In addition, g is the parameter of diffusion that influences to diffuse potential adopters.

$$\frac{dN(t)}{dt} = n(t) = g(m - N(t)) \quad (2)$$

The cumulative number of adopters, $N(t)$, gradually approaches m over time. The coefficient of diffusion, g, which influences to diffuse potential market can be divided into function of time or function of number of adopters. $g(t)$ can be characterized as three model, “external-influence” diffusion model, “internal-influence” diffusion model and “mixed-influence” diffusion model [43].

If coefficient of diffusion is constant, namely, $g(t)$ is constant p, the equation is called external- influence diffusion model. On the other hand, if coefficient of diffusion is affected by cumulative number of adopters, namely $g(t)$ is $qN(t)$, the equation is called internal-influence diffusion model. Finally, mixed-influence diffusion model considers the specifications of both external-influence diffusion model and internal-influence diffusion model, that is $g(t)$ is $p + qN(t)$ [44] (Although mixed-influence diffusion model provides a more realistic representation of the real-world process of innovation, it is not always more appropriate than external-influence diffusion model or internal-influence diffusion model. According to Kamakura and Balasubramanian (1988) [44], by the characteristics of new products/services, external-influence or internal-influence diffusion model explains and predicts better than mixed-influence diffusion model).

Especially, the internal-influence diffusion model which is affected only by internal effect is appropriate to model the diffusion of complex innovative products or technologies such as information and communication devices and technologies [45]. Technology convergence degree includes various and complex feature of innovation and its diffusion is considered to be rather influenced by the information formulated by existing users. Therefore, we selected internal-influence diffusion model among three diffusion models for the analysis.

Internal-influence diffusion model is divided into Logistic model and Gompertz model whether diffusion curve is bilateral symmetry. Gompertz model starts from each log modified form of potential market, m, and cumulative number of adopters, $N(t)$ in primary linear differential equation. Cumulative number of adopters $N(t)$ can be written as below from modified equation.

$$N(t) = me^{[-(\ln\frac{m}{N_0})e^{-q(t-t_0)}]} \tag{3}$$

While, Logistic model which is a primary linear differential equation of cumulative diffusion number $N(t)$ can be written as follows.

$$N(t) = \frac{m}{1 + \frac{(m - N_0)}{N_0} e^{-qm(t-t_0)}} \tag{4}$$

In comparison with the external-influence diffusion model, internal-influence diffusion model requires cumulative number of adopts at $t = 0$, N_0, suggesting that certain amount of adopters should exist for the activation of diffusion process.

We selected Logistic model as represent internal-influence diffusion model since the characteristic of Logistic model is the symmetry of its diffusion curve around the inflection point showing bell-shaped. In practice, our result of regression shows that RSS (Residual Sum of Squares) of Logistic model is lower than that of Gompertz model in most technologies.

Therefore, we introduce Logistic diffusion model to identify diffusion pattern of technology convergence as below.

$$TECH\_Y_{i(Inter-Field,\ Inter-Sector)} = \frac{b_1}{1 + \frac{(b_1 - b_0)}{b_0} e^{-b_2(t-t_0)}} \tag{5}$$

$TECH\_Y_i$ means technology convergence degree of technology classification i, that is aforementioned ratio of the number of convergence patents to the number of total patents. It can be classified into inter-field or inter-sector technology convergence depending on matching up IPC codes with technology classification. Because this paper applies general Logistic model not to product but to convergence, the terms of b_0, b_1, and b_2 can be defined by perspective on technology convergence linking original terms of Logistic model. Because the term of b_0 replaced N_0, *i.e.*, cumulative number of adopts at $t = 0$, b_0 can be defined as cumulative technology convergence at initial time, t_0 (This paper assumes that 1998 is initial time, t_0, in regression equation since we analyze diffusion pattern during 1998–2010). The term of b_1 and b_2 respectively replaced m (the potential number of ultimate adopters), and qm (growth of adopters). Therefore, when considering technology convergence, b_1 and b_2 indicate potential size of technology convergence and growth rate of technology convergence, respectively. We cannot estimate our model by using linear regression since Logistic diffusion model is following the non-linear *S*-curve. We therefore use a non-linear regression analysis to estimate coefficients of Logistic diffusion model.

3.2. Data

When considering the national differences in intellectual property law and patent system, homogeneous data from a single patent office may provide more rational and reliable solution [46]. In 2011, scale of patent applications filed by Korean Intellectual Property Office (KIPO) is 8.4% of worldwide applications, and KIPO ranks fourth following China (24.6%), the United States (23.5%), and Japan (16.0%) in the world. In addition, KIPO patents can be utilized to analyze technological trend as a crucial reference [47].

Meanwhile, many papers and reports to research convergence emerged in the late 1990s and early 2000s, and the advent of convergence phenomenon is presumed to be started in earnest from late 1990s [2,5,6,48]. This paper, therefore, uses the patent applications filed by the KIPO.

The patent information is extracted from the database of the Korea Institute of Patent Information (KIPI). The KIPI, governed by the KIPO commercially provides dumped official data of filed patents to the KIPO, accompanied with detailed information of the patents such as assignee, the number of claims, the number of inventors, IPC, and application date [17]. We collected overall 1,476,967 of patent applications from 1998 to 2010 by using the KIPI database in May 2012.

Before we use co-classification methodology based on the technology classification system, we need to examine the overall patent distribution in order to verify feasibility of methodology. The overall patent distribution indicates proportion of each sector (or field) that is calculated as a ratio of patent applications of each sector (or field) to total patent applications. Figure 2 shows patent distribution by technological sector, and electrical engineering sector accounts for 40% of total patent applications in 2010 followed by mechanical engineering, chemistry, instruments and other field. Since a patent can be included to the various technologies, the weighed share of each technological sector is not the absolute value but the relative value.

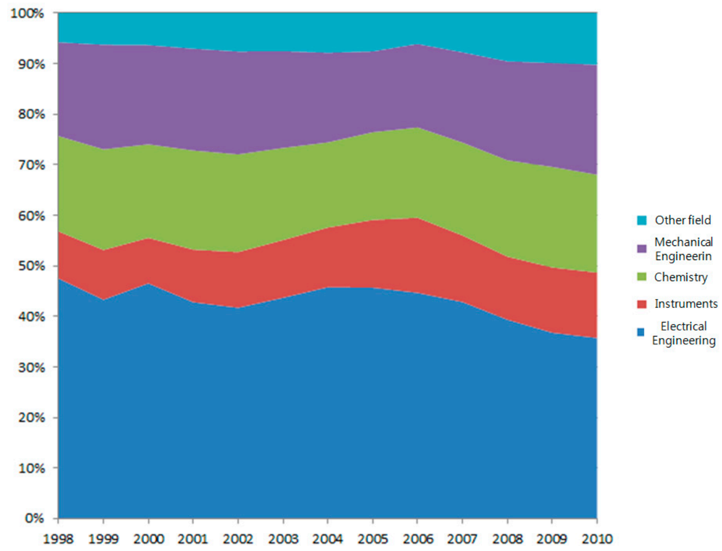


Figure 2. Trend of patent distribution in Korea according to sector classification.

In aspect of the technological field, as shown in Figure 3, share of IT Methods for Management in 2000 have sharply increased compare to 1999 due to advancement of IT technology in early 2000, and this field maintains 3% of total patent applications since 2002.

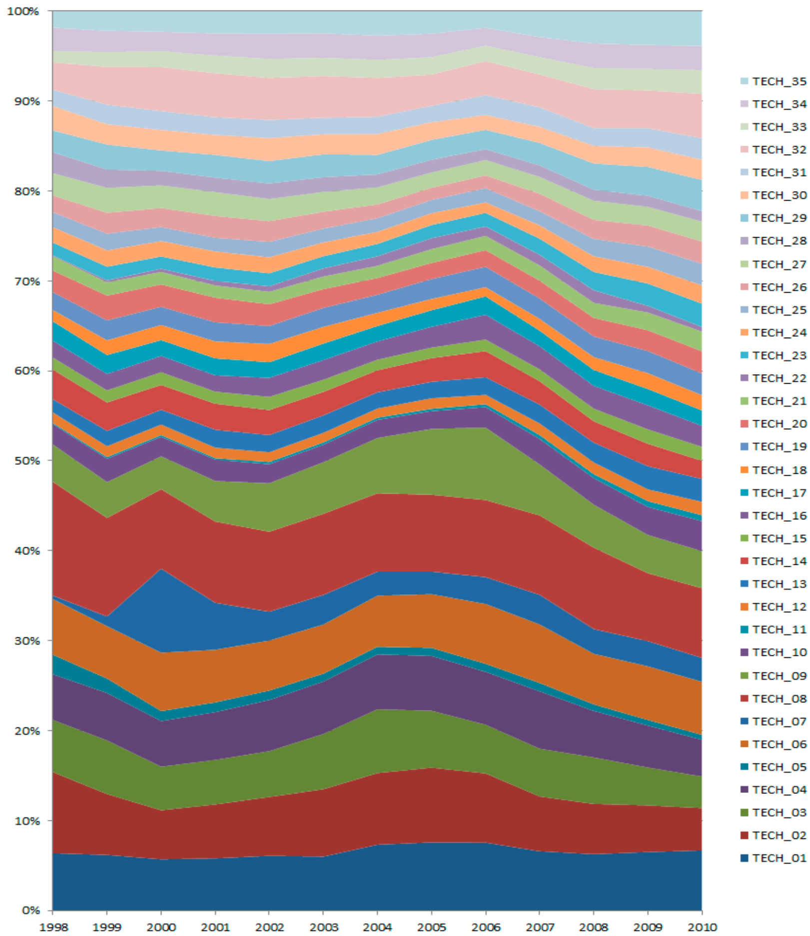


Figure 3. Trend of patent distribution in Korea according to field classification.

Patent distribution does not show a severe bias, since patent in almost fields except for IT management system has not experienced moderate change over time, and that in sector also has not shown a great change. Therefore, a co-classification methodology can be used to analyze technology convergence.

4. Result and Discussion

4.1. Regression Results of Diffusion Model

Based on the result of technology convergence degree, this paper estimated each technology's diffusion curve by using Logistic diffusion model, which the results are shown in Tables 3 and 4.

As an estimation result of diffusion curve for inter-field technology convergence as shown in Table 3, a coefficient of potential size of technology convergence (b_1) is significantly larger in Bio-material analysis (TECH_11) and Macromolecular Chemistry/Polymers (TECH_17), but smaller in audio/visual (TECH_02) and Computer technology (TECH_06) than others. When considering that technology convergence degree of audio/visual and computer technology is not significantly lower than others in 1998–2010, the reason why audio/visual and computer technology has lower potential size of technology convergence is that their convergences were progressed in advance and reached to the stable stage comparing to others.

Table 3. Regression result of diffusion curve for inter-field technology convergence.

Sector	Field	Technology Convergence at Initial Time (b_0)	Potential Size of Technology Convergence (b_1)	Growth Rate of Technology Convergence (b_2)
Electrical Engineering	TECH 01 Electrical machinery, Apparatus, Energy	0.0106 ***	0.4887 ***	0.4928 ***
	TECH 02 Audio-Visual Technology	0.0027	0.4437 ***	0.7781 ***
	TECH 03 Telecommunications	0.0600 **	0.7239 ***	0.3604 ***
	TECH 04 Digital Communication	0.0974 ***	0.5128 ***	0.3405 ***
	TECH 05 Basic Communication Processes	0.0150	0.4820 ***	0.5827 ***
	TECH 06 Computer Technology	0.0248 ***	0.4529 ***	0.4455 ***
	TECH 07 IT Methods for Management	0.0497 ***	1.0000	0.1782 ***
	TECH 08 Semiconductors	0.0086 ***	0.5781 ***	0.4125 ***
Instruments	TECH 09 Optics	0.0030 **	0.5434 ***	0.6745 ***
	TECH 10 Measurement	0.0237	0.7440 ***	0.4126 ***
	TECH 11 Analysis of Biological Materials	0.0579 **	0.9154 ***	0.4643 ***
	TECH 12 Control	0.0134	0.6397 ***	0.5441 ***
	TECH 13 Medical Technology	0.0263 ***	1.0000	0.2804***
Chemistry	TECH 14 Organic Fine Chemistry	0.0157 **	0.6958 ***	0.5778 ***
	TECH 15 Biotechnology	0.0569 ***	1.0000	0.2893 ***
	TECH 16 Pharmaceuticals	0.0344	0.5990 ***	0.5262 ***
	TECH 17 Macromolecular Chemistry/Polymers	0.0376 ***	0.8043 ***	0.5132 ***
	TECH 18 Food Chemistry	0.0084	1.0000	0.3712 ***
	TECH 19 Basic Materials Chemistry	0.0474 ***	1.0000	0.3219 ***
	TECH 20 Materials/Metallurgy	0.0333 **	0.6295 ***	0.4905 ***
	TECH 21 Surface Technology/Coating	0.0247 **	0.7433 ***	0.5113 ***
	TECH 22 Micro-structural and/Nano-technology	0.9070 ***	1.0000	−0.0437
	TECH 23 Chemical Engineering	0.0713 ***	0.7995 ***	0.3767 ***
	TECH 24 Environmental Technology	0.0261 ***	1.0000	0.3687 ***
Mechanical Engineering	TECH 25 Handling	0.0192 **	1.0000	0.3720 ***
	TECH 26 Machine Tools	0.0089	0.4926 ***	0.5244 ***
	TECH 27 Engines/Pumps/Turbines	0.0126	0.5374 **	0.3896 ***
	TECH 28 Textile/Paper Machines	0.0160	0.5039 ***	0.4636 ***
	TECH 29 Other special Machines	0.0068	0.5462 ***	0.7750 ***
	TECH 30 Thermal Processes and Apparatus	0.0091 **	1.0000	0.3892 ***
	TECH 31 Mechanical Elements	0.0374 ***	0.7593 ***	0.3555 ***
	TECH 32 Transport	0.0123 **	1.0000	0.3597 ***
Other fields	TECH 33 Furniture/Games	0.0120	0.9685	0.3380 **
	TECH 34 Other Consumer Goods	0.0107	0.4704 ***	0.4021 ***
	TECH 35 Civil Engineering	0.0081	0.7521	0.4043 ***

Note: ** and *** indicate significance level at 5% and 1%, respectively.

Table 4. Regression result of diffusion curve for inter-sector technology convergence.

Sector	Field	Technology Convergence at Initial Time (b_0)	Potential Size of Technology Convergence (b_1)	Growth Rate of Technology Convergence (b_2)
Electrical Engineering	TECH 01 Electrical machinery, Apparatus, Energy	0.0166 ***	0.5074 ***	0.3339 ***
	TECH 02 Audio-Visual Technology	0.0002	0.2058 ***	0.9915 ***
	TECH 03 Telecommunications	0.0024 **	0.0898 ***	0.4183 ***
	TECH 04 Digital Communication	0.0059 ***	0.0912	0.1926 ***
	TECH 05 Basic Communication Processes	0.0015	0.0850 ***	0.5164 ***
	TECH 06 Computer Technology	0.0067 ***	0.1236 ***	0.5046 ***
	TECH 07 IT Methods for Management	0.0023 ***	1.0000	0.2927 **
	TECH 08 Semiconductors	0.0089 ***	0.6127 ***	0.3561 ***
Instruments	TECH 09 Optics	0.0026 **	0.5063 ***	0.6970 ***
	TECH 10 Measurement	0.0267 **	0.6559 ***	0.3409 ***
	TECH 11 Analysis of Biological Materials	0.0315	0.5320 ***	0.5723 ***
	TECH 12 Control	0.0174 ***	0.5288 ***	0.4838 ***
	TECH 13 Medical Technology	0.0243 ***	1.0000	0.2683 ***
Chemistry	TECH 14 Organic Fine Chemistry	0.0030 ***	1.0000	0.3261 ***
	TECH 15 Biotechnology	0.0164 **	0.9405	0.2437 **
	TECH 16 Pharmaceuticals	0.0044	0.0702	0.3025 **
	TECH 17 Macromolecular Chemistry/Polymers	0.0254 ***	0.6153 ***	0.4723 ***
	TECH 18 Food Chemistry	0.0036	0.3542	0.3644 ***
	TECH 19 Basic Materials Chemistry	0.0196 ***	1.0000	0.2994 ***
	TECH 20 Materials/Metallurgy	0.0299 **	0.4322 ***	0.3896 ***
	TECH 21 Surface Technology/Coating	0.0163 **	0.5900 ***	0.5088 ***
	TECH 22 Micro-structural and/Nano-technology	0.4668 ***	1.0000	0.0284
	TECH 23 Chemical Engineering	0.0309 ***	0.7216	0.2625 ***
	TECH 24 Environmental Technology	0.0100	0.8641	0.3535 ***
Mechanical Engineering	TECH 25 Handling	0.0129	0.6753 ***	0.3943 ***
	TECH 26 Machine Tools	0.0035	0.3043 ***	0.6451 ***
	TECH 27 Engines/Pumps/Turbines	0.0049	0.2365 ***	0.4356 ***
	TECH 28 Textile/Paper Machines	0.0100	0.3872 ***	0.5432 ***
	TECH 29 Other special Machines	0.0041	0.4689 ***	0.8554 ***
	TECH 30 Thermal Processes and Apparatus	0.0059	0.6713	0.4036 ***
	TECH 31 Mechanical Elements	0.0283 ***	0.3508 ***	0.3403 ***
	TECH 32 Transport	0.0072	0.7777	0.3545 ***
Other fields	TECH 33 Furniture/Games	0.0104	0.8949	0.3289 **
	TECH 34 Other Consumer Goods	0.0075	0.3447 ***	0.4637 ***
	TECH 35 Civil Engineering	0.0077	0.7084	0.4018 ***

Note: ** and *** indicate significance level at 5% and 1%, respectively.

Meanwhile, in the case of inter-sector technology convergence as shown in Table 4, Handling (TECH_25), Measurement (TECH_10) and Macromolecular Chemistry/Polymers (TECH_17) show larger potential size of technology convergence whereas Basic communication process (TECH_05), Telecommunication (TECH_03) and Computer technology (TECH_06) were estimated to have smaller potential size of technology convergence. This small potential size of communication technologies may result from not only mature progress of technology convergence, but also technological characteristic that is difficult to occur inter-sector technology convergence since these technologies are original and basic Information and Communication Technology (ICT).

As a result of growth rate of technology convergence (b_2), inter-field technology convergence of Audio/visual (TECH_02), Other special machines (TECH_29) and Optics (TECH_09), are growing rapidly, whereas IT Methods for Management (TECH_07), Medical Technology (TECH_13) and Basic Materials Chemistry (TECH_19) show a slower growth than others. In the case of inter-sector technology convergence, Audio/visual (TECH_02), other special machines (TECH_29) and Optics (TECH_09) have higher growth rate, whereas Digital communication (TECH_04), Biotechnology (TECH_15) and Chemical Engineering (TECH_23) are experiencing slow growth.

From Figures 4 and 5 one can understand more details of relationship between the growth rate of technology convergence (b_2, y-axis) against potential size of technology convergence (b_1, x-axis).

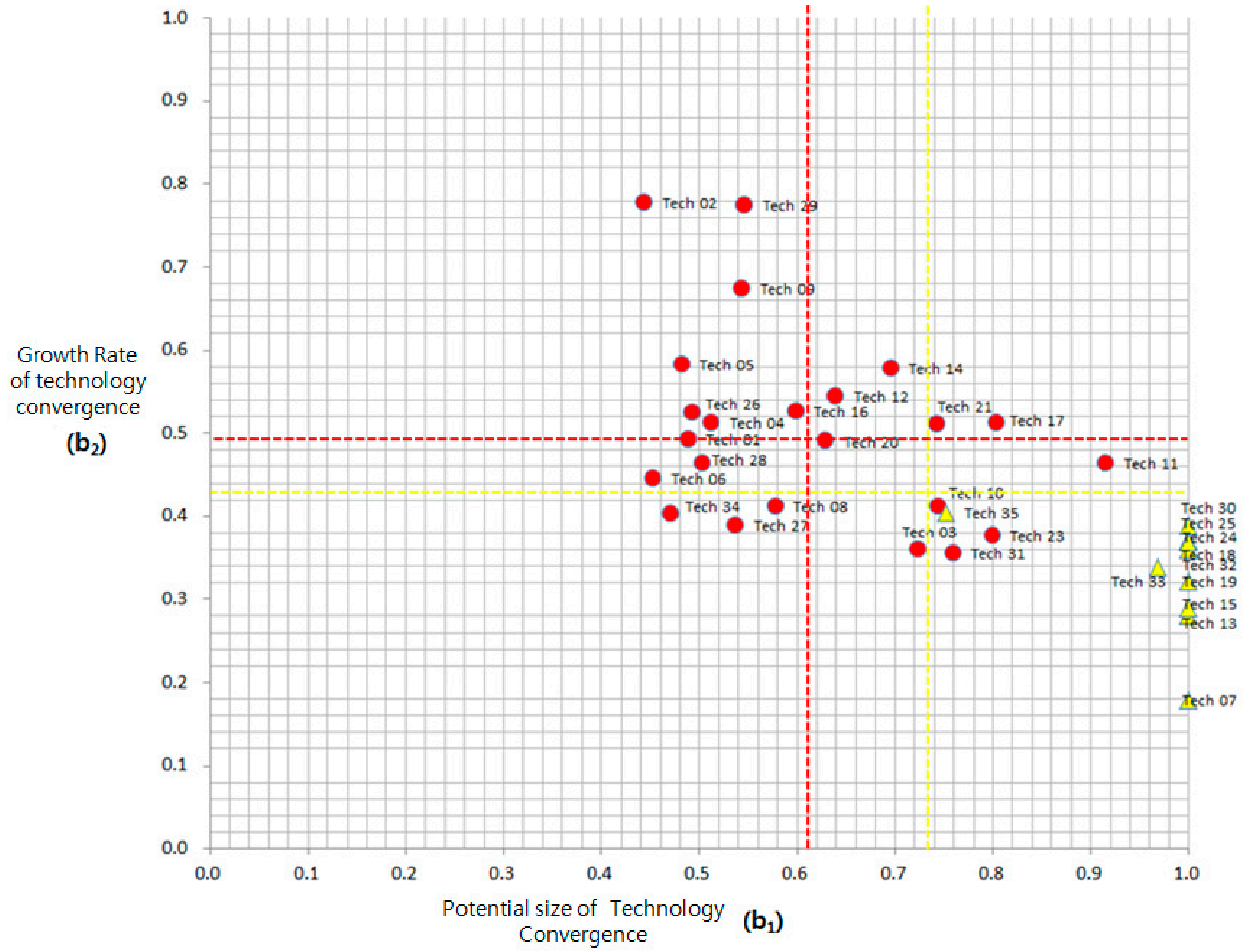


Figure 4. Distribution of potential size (b_1) and growth rate (b_2) in inter-field technology convergence. (Note: A mark of "triangle" means that regression coefficient is not significant. In addition, a red dotted line indicates a mean value of each axis including only statistically significant technologies, while a yellow dotted line means a mean value of each axis including both significant and non-significant technologies).

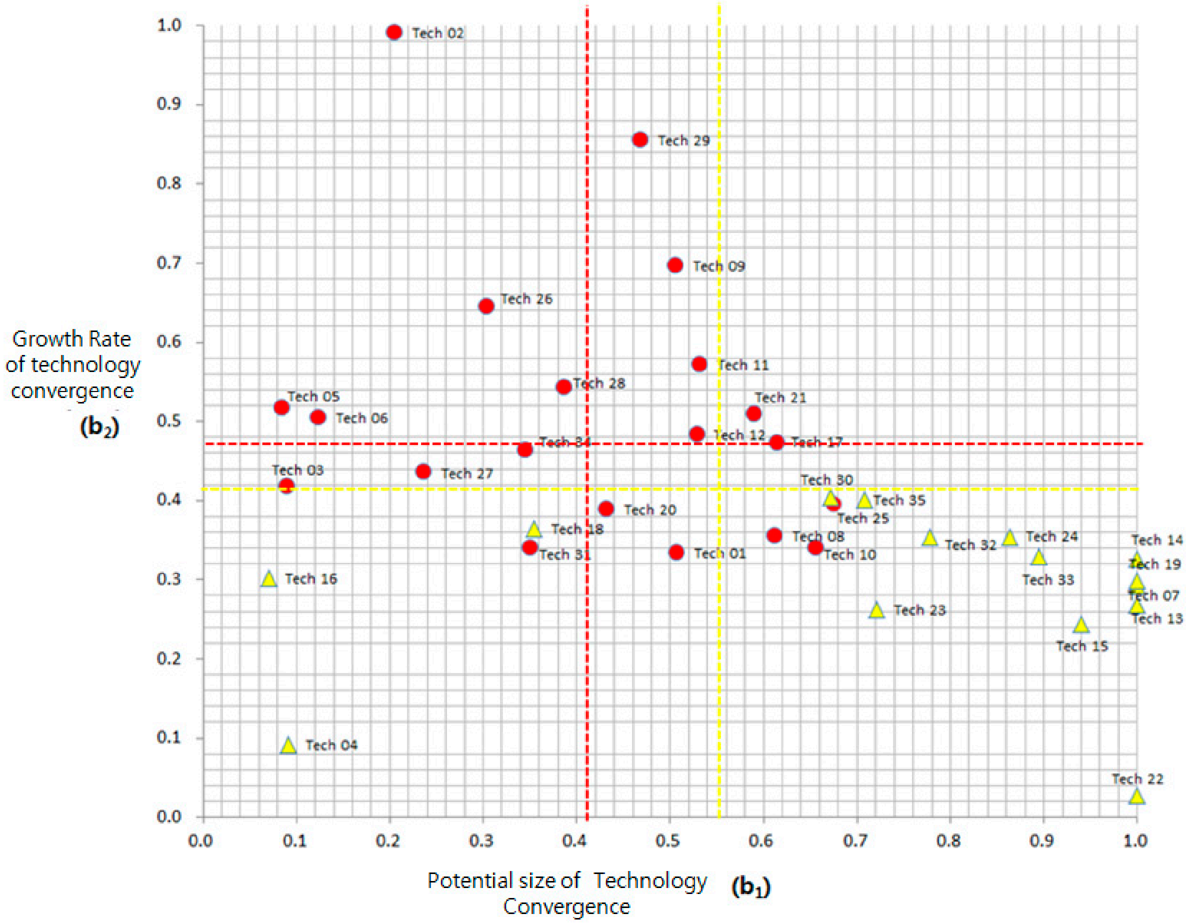


Figure 5. Distribution of potential size (b_1) and growth rate (b_2) in inter-sector technology convergence. (Note: A mark of "triangle" means that regression coefficient is not significant. In addition, a red dotted line indicates a mean value of each axis including only statistically significant technologies, while a yellow dotted line means a mean value of each axis including both significant and non-significant technologies).

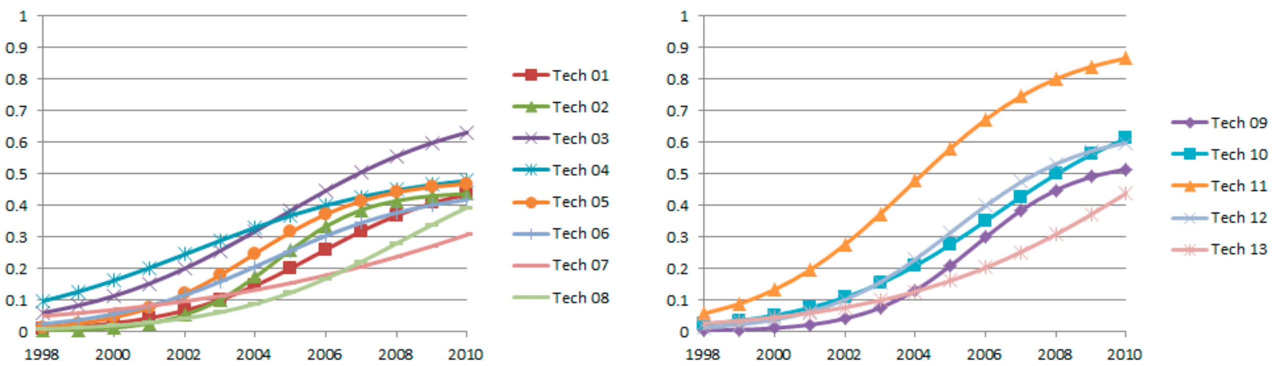
As shown in Figures 5 and 6, in inter-field technology convergence, the 35 technologies are intensively distributed around a mean value of each axis, while they are widely distributed in inter-sector technology convergence. This suggests that diffusion pattern of inter-sector technology convergence appears as the more various form than that of inter-field technology convergence. Nevertheless, growth rate of technology convergence is in inverse proportion to potential size of technology convergence in common. That is, the faster the growth rate of technology convergence, the smaller the potential size of technology convergence, although a relationship between potential size and growth rate is varied by technology and convergence type.

In discussion of the quadrant divided by a mean value of each axis, *i.e.*, a red dotted line in Figures 5 and 6, we focus on the technologies which are statistically significant and have a similar tendency in inter-field and inter-sector technology convergence (This diffusion pattern analysis has a limitation that we consider not the total diffusion pattern for the all 35 technologies but only that for statistically significant technologies on both b_1 and b_2). Technologies in the first quadrant which has relatively large potential size as well as high growth rate are Control (TECH_12), Macromolecular Chemistry/Polymers (TECH_17) and Surface treat/coating (TECH_21) in the instrument and chemistry sectors. The second quadrant meaning that their growth rate of technology convergence increases, while their potential size of technology convergence relatively decreases have technologies in mainly the electrical engineering sector including Audio/visual (TECH_02), Basic Communication Process (TECH_05), Machine Tool (TECH_26) and so on. Technologies in the third quadrant which indicates decreases in both growth rate and potential size are Engines/Pump/turbine (TECH_27) and other Consumer Goods (TECH_34) in the mechanical engineering and other fields sector. Lastly, the fourth quadrant meaning that growth rate of technology convergence is low while potential size is relatively high has technologies in the instrument and chemistry categories including Measurement (TECH_10), Materials/Metallurgy (TECH_20) and so on.

When considering results of both inter-field and inter-sector technology convergence, one can infer that technology related to ICT in electrical engineering sector has relatively lower potential size, while instrument and chemistry sector have relatively high potential size. These results come from aforementioned well-developed convergence stage of the Electrical Engineering sector and coincide with a perception that ICT conventionally has been regarded as the majority of technology convergence [7].

4.2. Analysis of Diffusion Pattern

By using the result of Tables 3 and 4, we estimated diffusion curves of convergence by each technology during 1998 to 2010. Figures 6 and 7 show diffusion curve of inter-field and inter-sector technology convergence for thirty four technologies (Illustrating Figures 6 and 7 with an example, the shape of Telecommunications (TECH_03) in Figure 6 describes diffusion of convergence between Telecommunications and technologies in electrical engineering. While, that in Figure 7 shows diffusion of convergence between Telecommunications and technologies in other sector such as instruments, chemistry, and mechanical engineering. This paper excludes diffusion analysis of Micro-structural and/Nano-technology (TECH_22) since its technology convergence degree was calculated as almost 1 and an estimation result of its diffusion curve shows non-significance in all parameters), respectively.



(a) **(b)**

Figure 6. *Cont.*

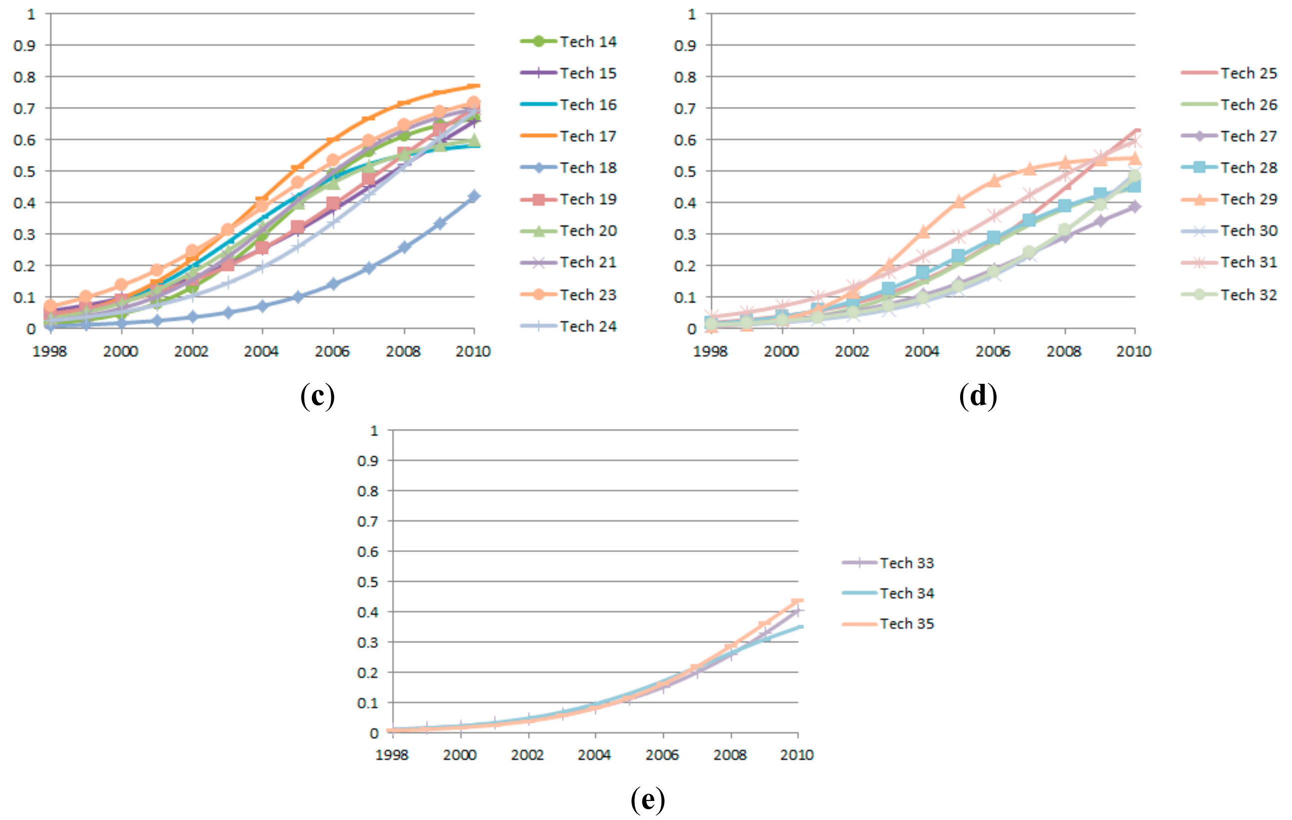


Figure 6. (**a**) Electrical Engineering; (**b**) Instruments; (**c**) Chemistry; (**d**) Mechanical Engineering; (**e**) Other fields. Diffusion curve of inter-field technology convergence. (Note: The Y-axis indicates technology convergence degree.)

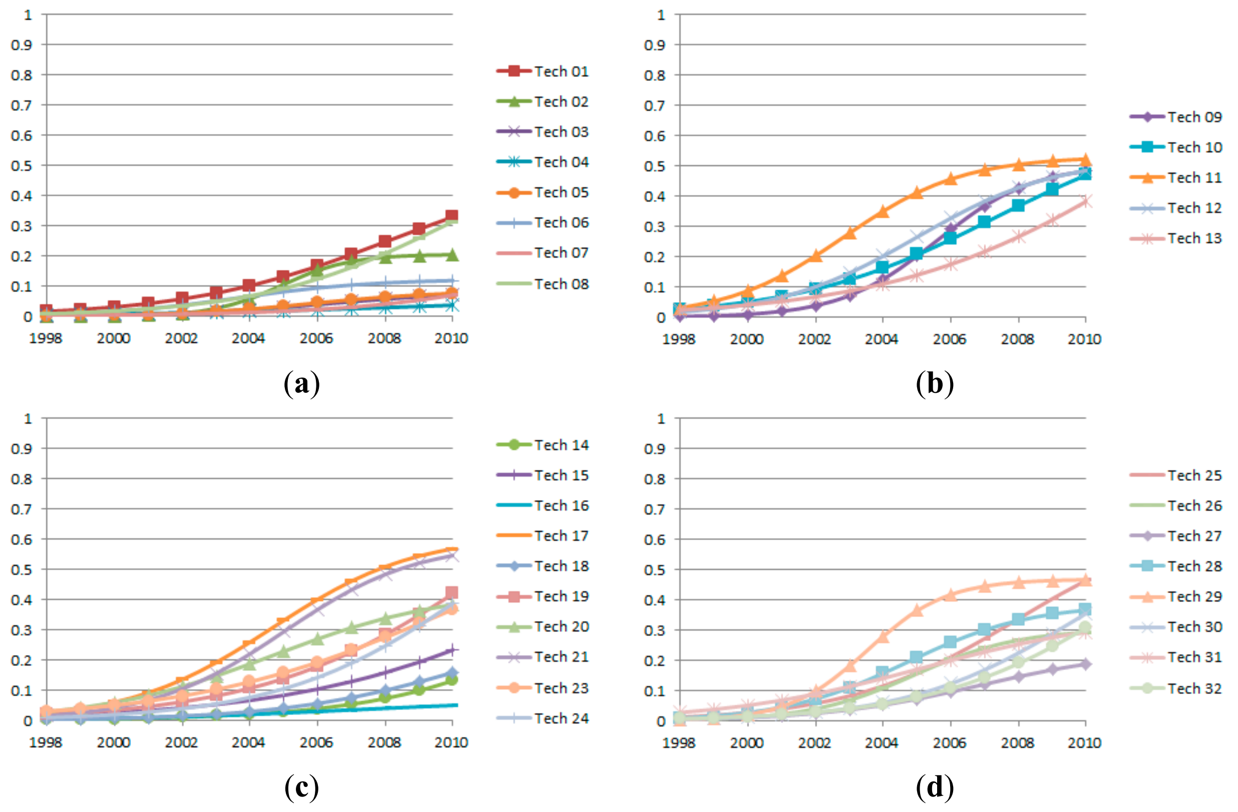
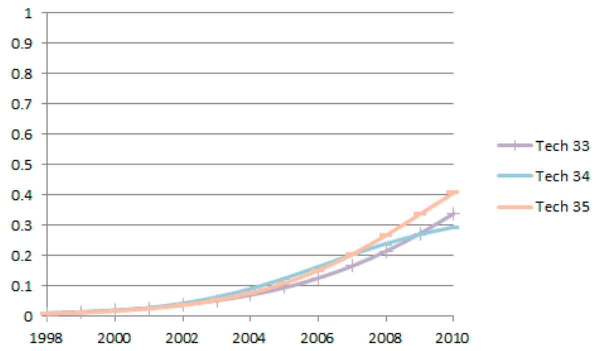


Figure 7. *Cont.*



(e)

Figure 7. (**a**) Electrical Engineering; (**b**) Instruments; (**c**) Chemistry; (**d**) Mechanical Engineering; (**e**) Other fields Diffusion curve of inter-sector technology convergence. (Note: The Y-axis indicates technology convergence degree.)

As interpretation of diffusion curve, inter-field technology convergence in almost technologies has sharply increased since early 2000 and its degree is approximately 12% (By using the coefficient of b_1 and b_2 for each technology, we estimated technology convergence degree by each technology during 1998 to 2010 and calculated an average value of thirty five technologies.) higher than that of inter-sector technology convergence. Even though the technology sector is homogeneous, the progress of convergence is varied by technology.

In 2010, Analysis of Bio-material (TECH_11) shows the highest degree of inter-field technology convergence and Macromolecular Chemistry/Polymers (TECH_17), Chemical Engineering (TECH_23) and Telecommunications (TECH_03) followed. While IT Methods for Management (TECH_07) and other consumer Goods (TECH_34) are low degree of inter-field technology convergence. Technology to have the highest degree of inter-field technology convergence by the five technology categories is Telecommunications (TECH_03) in the Electrical Engineering, Analysis of Bio-material (TECH_11) in the Instrument, Macromolecular Chemistry/Polymers (TECH_17) in the Chemistry, Handing (TECH_25) in the Mechanical Engineering, Civil engineering (TECH_35) in the other field.

Table 5 accounts for top rank technologies of the highest technology convergence degree and bottom rank technologies of the lowest technology convergence degree according to type of convergence in 2010. As shown in Table 5, degree of inter-sector technology convergence of Macromolecular Chemistry/Polymers (TECH_17) ranks the highest in 2010 and Surface treat/coating (TECH_21) and Analysis of Bio-material (TECH_11) followed. While Digital communication (TECH_17) and Medicine (TECH_16) which are relatively original and basic technology show the lowest degree of inter-sector technology convergence. Electrical machinery, Apparatus, Energy (TECH_01), Analysis of Bio-material (TECH_11), Macromolecular Chemistry/Polymers (TECH_17), other special machines (TECH_29) and Civil engineering (TECH_35) have the highest degree of inter-sector technology convergence in each technology category.

To summarize these results, one can infer that technology convergence of instrument and chemistry sector is actively progressing in both inter-field and inter-sector convergence, which comes from the early development stage of technology convergence in instrument and chemistry sector. On the other hand, the technologies related to ICT in electrical engineering sector have relatively mature progress of technology convergence, especially in inter-sector technology convergence. This surprising findings provides an evidence that bio-chemistry sector is a majority of technology convergence following the conventional ICT. In fact, convergence between Telecommunications and Digital Communication, so called "digital enhanced cordless telecommunications" [49], had received attention in Korea until early 2000s but in recent convergence between Organic Fine Chemistry and Pharmaceuticals that can represent the advance of "pharmaceutical fine chemistry" [50] is rapidly rising.

Table 5. Comparison of diffusion pattern of technology convergence (2010).

	Type of Convergence	Top Rank	Bottom Rank
Total	Field	TECH 11 Analysis of Biological Materials TECH 17 Macromolecular Chemistry/Polymers	TECH 07 IT Methods for Management TECH 34 Other Consumer Goods
	Sector	TECH 17 Macromolecular Chemistry/Polymers TECH 21 Surface Technology/Coating TECH 11 Analysis of Biological Materials	TECH 04 Digital Communication TECH 16 Pharmaceuticals
Electrical Engineering	Field	TECH 03 Telecommunications	TECH 07 IT Methods for Management
	Sector	TECH 01 Electrical machinery, Apparatus, Energy	TECH 04 Digital Communication
Instruments	Field	TECH 11 Analysis of Biological Materials	TECH 13 Medical Technology
	Sector	TECH 11 Analysis of Biological Materials	TECH 13 Medical Technology
Chemistry	Field	TECH 17 Macromolecular Chemistry/Polymers	TECH 18 Food Chemistry
	Sector	TECH 17 Macromolecular Chemistry/Polymers	TECH 16 Pharmaceuticals
Mechanical Engineering	Field	TECH 25 Handling	TECH 27 Engines/Pumps/Turbines
	Sector	TECH 29 Other special Machines	TECH 27 Engines/Pumps/Turbines
Other fields	Field	TECH 35 Civil Engineering	TECH 34 Other Consumer Goods
	Sector	TECH 35 Civil Engineering	TECH 34 Other Consumer Goods

5. Conclusions

This paper estimated the potential size and growth rate of technology convergence diffusion by using data of patent applications in Korea. In short, potential size and growth rate are varied by both technology and type of technology convergence, *i.e.*, inter-field and inter-sector technology convergence. When considering results of both inter-field and inter-sector technology convergence, one can infer that technology related to instrument and chemistry sector have relatively larger potential size, while ICTs in electrical engineering sector have relatively smaller than others. Regarding growth rate, some of electrical engineering and instrument sector including Audio/visual (TECH_02), other special machines (TECH_29) and Optics (TECH_09) show relatively faster growth, while chemistry sector including Biotechnology (TECH_15), Materials Chemistry (TECH_19) and Chemical Engineering (TECH_23) has relatively lower growth rate.

A result of diffusion pattern provides an evidence that diffusion pattern of inter-sector technology convergence appears as the more various form than that of inter-field technology convergence. In addition, a relationship between potential size and growth rate of technology convergence tell us that growth rate of technology convergence is in inverse proportion to potential size of technology convergence in general.

This paper also estimated diffusion curves of convergence by each technology during 1998 to 2010. The result shows that inter-field technology convergence in almost technologies has sharply increased since early 2000 and its degree of convergence is generally higher than that of inter-sector technology convergence, although the progress of convergence is varied by technology. One can infer that technology convergence of the instrument and chemistry sector is actively progressing in both inter-field and inter-sector convergence, which comes from the early development stage of technology convergence in the instrument and chemistry sector. On the other hand, the technologies related to ICT in electrical engineering sector have relatively mature progress of technology convergence, especially in inter-sector technology convergence.

However, with these important findings, this paper has several limitations. First, this paper measures technology convergence by using IPC classification, but it has a limitation that IPC cannot show quality of patent or accurate/direct information of technology convergence. That is, since this paper cannot measure qualitative information of patents, non-convergent patent may be included in patents identified as a convergent patent. Second, despite the strong empirical evidence for the pattern of technology convergence, this paper cannot provide its underlying reasons. We infer that social factors as well as technological factors such as change of social demand, industrial change and technological development may be important causes. In the future, follow-up empirical demonstrations of factors to affect technology convergence may give entire picture on technology convergence.

Despite several limits, this paper provides basic knowledge about diffusion pattern of technology convergence. This paper emphasizes that technology convergence has developed with a positive growth rate every year since early 2000 and is recently progressing with more complex and more various patterns. In addition, the result of this paper can support validity of current strategy and policy carried out by firm and government. That is, from this paper, one can understand current state of technology convergence and predict future trend. Moreover, policy makers can know where intensive convergence will occur in the future and establish convergence diffusion strategy for each technology.

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Author Contributions

All three authors contributed to the completion of the research. Jae Young Choi contributed to the concept and design of the paper and drew the outline of the paper. Seongkyoon Jeong contributed to methodology and data work. Kyunam Kim contributed to analyze the data and modified the draft. Jae Young Choi and Kyunam Kim were in charge of the final version of the paper. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Dolata, U. Technological innovations and sectoral change. *Res. Policy* **2009**, *38*, 1066–1076.
2. Lei, D.T. Industry evolution and competence development: The imperatives of technology convergence. *Int. J. Technol. Manag.* **2000**, *19*, 699–738.
3. Yoffie, D.B. Competing in the age of digital convergence. *Calif. Manag. Rev.* **1996**, *4*, 31–53.
4. Baer, M. *Kooperationen und Konvergenz*; Peter Lang GmbH: Frankfurt, Germany, 2004.
5. Katz, M.L. Remarks on the economic implications of convergence. *Ind. Corp. Chan.* **1996**, *5*, 1079–1095.
6. Athreye, S.; Keeble, D. Technology convergence, globalisation and ownership in the UK computer industry. *Technovation* **2000**, *20*, 227–245.
7. Curran, C.S.; Leker, J. Patent indicators for monitoring convergence—examples from NFF and ICT. *Technol. Forecast. Soc. Chang.* **2011**, *78*, 256–273.
8. Roco, M.C.; Bainbridge, W.S. Converging Technologies for Improving Human Performance. Arlington, Virginia: National Science Foundation. Available online: http://www.nsf.gov/crssprgm/nano/activities/ct05_flyer_rev54.pdf (accessed on 12 August 2015).
9. Hacklin, F. *Management of Convergence in Innovation: Strategies and Capabilities for Value Creation beyond Blurring Industry Boundaries: Contributions to Management Science*; Springer: Berlin, Germany, 2008.
10. Hacklin, F.; Wallin, M.W. Convergence and interdisciplinarity in innovation management: A review, critique, and future directions. *Serv. Ind. J.* **2013**, *33*, 774–788.
11. Nordmann, A. *Converging Technologies—Shaping the Future of European Societies*; Office for Official Publications of the European Communities (EUR 21357): Luxembourg, 2004.
12. Borés, C.; Saurina, C.; Torres, R. Technology convergence: A strategic perspective. *Technovation* **2003**, *23*, 1–13.
13. Curran, C.S. *The Anticipation of Converging Industries*; Springer: London, UK, 2013.
14. Karvonen, M.; Lehtovaara, M.; Kässi, T. Build-up of understanding of technology convergence: Evidence from printed Intelligence industry. *Int. J. Innov. Technol. Manag.* **2012**, *9*, doi:10.1142/S0219877012500204.
15. Preschitschek, N.; Curran, C.S.; Leker, J. The importance of access to resources in a setting of industry convergence: The case of agriculture and chemistry. In IEEE Proceedings of the Technology Management in the Energy Smart World (PICMET), 2011 PICMET'11, Portland, OR, USA, 31 July–4 August 2011; pp. 1–9.
16. Karvonen, M.; Kassi, T. Patent citations as a tool for analysing the early stages of convergence. *Technol. Forecast. Soc. Change* **2013**, *80*, 1094–1107.
17. Jeong, S.K.; Kim, J.C.; Choi, J.Y. Technology Convergence: What Developmental Stage Are We in? *Scientometrics* **2015**, doi:10.1007/s11192-015-1606-6.
18. Callon, M.; Law, J.; Rip, A. *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World*; MacMillan: London, UK, 1986.
19. Palmer, C. Structures and strategies of interdisciplinary science. *J. Am. Soc. Inf. Sci.* **1999**, *50*, 242–253.

20. Small, H. A co-citation model of a scientific specialty: A longitudinal study of collagen research. *Soc. Stud. Sci.* **1977**, *7*, 139–166.
21. Zitt, M.; Ramanana-Rahary, S.; Bassecoulard, E. Relativity of citation performance and excellence measures: From cross-field to cross-scale effects of field-normalisation. *Scientometrics* **2005**, *63*, 373–401.
22. Leydesdorff, L. Mapping interdisciplinarity at the interfaces between the Science Citation Index and the Social Science Citation Index. *Scientometrics* **2007**, *71*, 391–405.
23. Porter, A.L.; Rafols, I. Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics* **2009**, *81*, 719–745.
24. Porter, A.L.; Roessner, D.J.; Heberger, A.E. How interdisciplinary is a given body of research? *Res. Eval.* **2008**, *17*, 273–282.
25. Porter, A.L.; Cohen, A.S.; David Roessner, J.; Perreault, M. Measuring researcher interdisciplinarity. *Scientometrics* **2007**, *72*, 117–147.
26. Noyons, E.C.M.; van Raan, A.F.J. Monitoring scientific developments from a dynamic perspective: Self-organized structuring to map neural network research. *J. Am. Soc. Inf. Sci.* **1998**, *49*, 68–81.
27. Tijssen, R.J.W. A quantitative assessment of interdisciplinary structures in science and technology: Co-classification analysis of energy research. *Res. Policy* **1992**, *21*, 27–44.
28. Morillo, F.; Bordons, M.; Gomez, I. Interdisciplinarity in science: A tentative typology of disciplines and research areas. *J. Am. Soc. Inf. Sci. Technol.* **2003**, *54*, 1237–1249.
29. Schummer, J. Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology. *Scientometrics* **2004**, *59*, 425–465.
30. Geum, Y.; Kim, C.; Lee, S.; Kim, M. Technology convergence of IT and BT: Evidence from Patent Analysis. *ETRI J.* **2012**, *34*, 439–449.
31. Jeong, S.K. Strategic collaboration of R&D entities for technology convergence: Exploring organizational differences within the triple helix. *J. Manag. Org.* **2014**, *20*, 227–249.
32. Pennings, J.M.; Puranam, P. Market Convergence and firm strategy: New directions for theory and research. In Proceedings of the ECIS Conference, the Future of Innovation Studies, Eindhoven, The Netherland, 20–23 September 2001.
33. Fai, F.; von Tunzelmann, N. Industry-specific competencies and converging technological systems: Evidence from patents. *Str. Change Econ. Dyn.* **2001**, *12*, 141–170.
34. Curran, C.S.; Bröring, S.; Leker, J. Anticipating converging industries using publicly available data. *Technol. Forecast. Soc. Change* **2010**, *77*, 385–395.
35. Xing, W.; Ye, X.; Kui, L. Measuring convergence of China's ICT industry: An input-output analysis. *Telecommun. Policy* **2011**, *35*, 301–313.
36. Rafols, I.; Porter, A.; Leydesdorff, L. Science overlay maps: A new tool for research policy and library management. *J. Am. Soc. Inf. Sci. Technol.* **2010**, *61*, 1871–1887.
37. Wagner, C.S.; Roessner, J.D.; Bobb, K.; Klein, J.T.; Boyack, K.W.; Keyton, J.; Rafols, I.; Börner, K. Approaches to understanding and measuring interdisciplinary scientific research (IDR): A review of the literature. *J. Inf.* **2011**, *5*, 14–26.
38. Ernst, H. Patent information for strategic technology management. *World Pat. Inf.* **2003**, *25*, 233–242.

39. Gambardella, A.; Giuri, P.; Luzzi, A. The market for patents in Europe. *Res. Policy* **2007**, *36*, 1163–1183.
40. World Intellectual Property Organisation (WIPO). *Concept of a Technology Classification for Country Comparison*; WIPO: Karlsruhe, Germany, 2008.
41. Jaakkola, H. Comparison and Analysis of Diffusion Models. In *Diffusion and Adoption of Information Technology*; Kautzand, K., Pries-Heje, J., Eds.; Chapman & Hall: New York, NY, USA, 1996.
42. Mahajan, V.; Muller, E.; Bass, F.M. New Product Diffusion Models in Marketing: A Review and Directions for Research. *J. Mark.* **1990**, *54*, 1–26.
43. Mahajan, V.; Peterson, R. *Models for Innovation Diffusion*; Sage Publication: Beverly Hills, CA, USA, 1985.
44. Kamakura, W.A.; Balasubramanian, S.K. Long-Term View of the Diffusion of Durables: A Study of the Role of Price and Adoption Influence Process via Tests of Nested Models. *Int. J. Res. Mark.* **1988**, *5*, 1–13.
45. Sung, O.H. A Study on the Mid and Short Term Demand Forecasting of Information Technology Industry Market Using Growth and Diffusion Models. *Stat. Rev.* **2002**, *10*, 31–48.
46. Meyer, M. What is special about patent citations? Differences between scientific and patent citations. *Scientometrics* **2000**, *49*, 93–123.
47. WIPO. World Intellectual Property Indicators 2012 Edition. Available online: http://www.wipo.int/edocs/pubdocs/en/intproperty/941/wipo_pub_941_2012.pdf (accessed on 12 August 2015).
48. Gambardella, A.; Torrisi, S. Does technology convergence imply convergence in markets? Evidence from the electronics industry. *Res. Policy* **1998**, *27*, 445–463.
49. Tuttlebee, W.H.W. *Cordless Telecommunications Worldwide*; Springer: Berlin, Germany, 1996; ISBN 978-3-540-19970-0.
50. Stinson, S. Pharmaceutical fine chemicals. *CENEAR* **2000**, *78*, 63–80.