Submission to *Quality & Quantity* Special Issue Winter 2014/Spring 2015

Measuring the Dynamics of an Innovation System using Patent Data: A Case Study of South Korea, 2001-2010

22 March 2014

Authors
Pieter E. Stek
Marina S. van Geenhuizen, Ph.D. (corresponding author)

Affiliation (both authors)
Faculty of Technology, Policy and Management
Delft University of Technology

Address: Jaffalaan 5, 2628 BX Delft, The Netherlands
Tel: +31 15 278 6729
Fax: +31 15 278 3177
E-mail: m.s.vangeenhuizen@tudelft.nl

Abstract
The Korean innovation system is analyzed based on patenting and co-patenting behavior between different knowledge producers (university, government, small- and medium sized enterprises (SMEs), conglomerates, individuals) in 34 different technologies. Patent data is obtained from the Korean Intellectual Property Office (KIPO) for the years 2001-2010. The traditional triple-helix model of university-industry-government relations is expanded to include additional knowledge producers. The results indicate that the Korean innovation system has become less balanced in terms of technology: patent output has tended to grow rapidly in areas in which Korea is already strong. But the innovation system has become more balanced in terms of knowledge producers: SMEs, universities and individuals are being assigned an increasing number of patents. University patenting has grown most rapidly, especially in fast-growing technologies, in which university-business co-patenting is most prevalent. This suggests that rising public investment in university research is paying off, and that university research is industry-relevant. The data also reveal some unexpected changes: patenting by conglomerates rapidly rose from 2001, peaking in 2005, and then fell. Patenting by individuals has continued to rise throughout the period being studied.

Keywords
triple-helix; innovation; South Korea; patents; university-industry collaboration

1 INTRODUCTION

Korea has rapidly industrialized during the second half of the twentieth century and, in the 2000s, has been passing from the 'catch-up' stage towards becoming an advanced industrialized state (Wong 1999; Fagerberg and Godinho 2005; Mahlich and Pascha 2007). This development has also been experienced by other newly advanced economies in Asia, such as Singapore and Taiwan. Although the transition to innovation is similar, the three countries are facing different challenges due to their significantly different catch-up industrialization models (Wong 1999; Hsieh 2011). What makes Korea's situation unique is the presence of large, horizontally integrated business groups, conglomerates, which play a dominant role in the country's national innovation system, examples include: Samsung, LG (formerly Lucky Goldstar), Hyundai Motor, SK (formerly Sunkyoung) and Lotte (Hemmert 2007; Yurtoglu 2007; Eom and Lee 2010). However, in all three countries government policy has been critical in facilitating R&D to enable catch-up industrialization (Wong 1999; Hsieh 2011). Thus upon completion of its 'catch-up' phase, the national innovation system of Korea depended heavily on conglomerates and government research institutions (Kim 1997; Eom and Lee 2010).

The analysis of innovation systems often occurs at a national, aggregated scale, frequently on the basis of surveys or bibliometric data derived from scientific publications such as academic papers and patents. A popular framework for analysis is Etzkowitz and Leydesdorff's (2000) Triple Helix model of university-industry-government relationships. Central to the Triple Helix model is the idea that, while the sectors are autonomous, their collaboration, sometimes partly integration of each other's tasks, and a common orientation on the near future, are often an important enhancing factor of successful innovation. Therefore in Korea's national innovation system the over-reliance on government and conglomerates is a potentially limiting factor. While the Triple Helix model focuses on collaboration between the three main sectors, a fourth strand, such as international partners (Kwon et al. 2012; Leydesdorff and Sun 2009) or strong domestic user groups (van Geenhuizen 2013), is sometimes added to supplement the analysis.

In the Korean case, large conglomerates can be considered as a separate "strand" of the Triple ("Quadruple") Helix model because their methods of knowledge production, specifically their relatively long R&D investment horizons (Yurtoglu 2007), high propensity to collaborate with universities and government research institutes (GRIs) (Eom and Lee 2010), and dominant position in the domestic market, set them apart from small- and medium sized enterprises (SMEs). Yet there is little research about the knowledge production and collaboration behavior of large conglomerates in different areas of technology, and how this behavior is changing over time. Given Korea's attempts to broaden the base of its innovation system and a sustained national discourse about the economic, social and political impact of large conglomerates within Korea, the position of conglomerates as well as that of small and medium-sized enterprises within the national innovation system is an area of significant academic and social interest.

Therefore this paper seeks to address two main research questions: (1) Which changes have taken place in relative strength of *knowledge producers* in Korea's innovation system in the past decade and which patterns of collaboration between them have emerged? (2) How do these changes differ between *technology fields* and what does this mean in terms of a more balanced development?

In responding to the research questions, Korean knowledge production is investigated in the years from 2001 to 2010 as this is a period of significant policy changes aimed at improving the research capabilities of universities and SMEs and also of Korea's attempt to enter new fields of technology. In contrast to previous bibliometric studies on Korea, such as those by Kwon et al. (2012) and Park and Leydesdorff (2010), in this study patent data are used and analyzed at the level of individual knowledge producers like conglomerates, government, universities, etc., allowing to picture how they interact in different areas of technology. This cross-technology comparison is especially useful for the Korean case, because the role of conglomerates in the innovation process, and specifically in which technologies they are successful, becomes much clearer.

This paper first provides further background about Korean R&D policy, which is driving changes in the national innovation system (section 2). Based on these insights, hypotheses are formulated about the dynamics of Korea's national innovation system using the Triple Helix model (section 3). Subsequently, the methodology for classifying the patent data is presented, which is prefaced by a discussion on the strengths and weaknesses of using patent data as an indicator of knowledge production and research collaboration (section 4). This leads into the analysis and results of hypotheses testing (section 5), and the conclusion (section 6).

2 KOREAN R&D POLICY 2001-2010

The Korean knowledge production system was until the 1990s predominantly a "double helix", with strong collaboration between government research institutes and large conglomerates (Kim 1997; Eom and Lee 2010). Universities, the "third strand" in Etzkowitz and Leydesdorff's (2000) Triple Helix model of university-industry-government collaboration, played a marginal role (*ibid*). This situation can be understood in the context of Korea's catch-up industrialization process whereby the government guided economic activity and supported the acquisition of foreign technology to develop domestic industries (Amsden 1992; Woo 1991; Kim 1997). At that time, Korean universities primarily functioned as undergraduate teaching institutions and most researchers were educated abroad (Kim 1997).

In the period being studied, 2001-2010, a number of significant changes occurred in

Korea's innovation system. The most significant ones have affected Korean universities, the missing "third strand" of the Triple Helix model. Following the East Asian Financial Crisis of 1997-1998 the Kim Dae-Jung administration launched the Brain Korea 21 (BK21) project to stimulate research at universities. BK21 was much larger than previous government support for university research. Whereas in 1993 the government provided 20 billion won ($24.2 million) of funding fourteen university-based Science Research Centers and sixteen Engineering Research Centers (Kim 1997), the first BK21 project had a budget of 200 billion won per year ($171 million), totaling an investment of 1.34 trillion won ($1.2 billion) over seven years to 564 different research teams (Moon and Kim 2001; Seong et al. 2008). Overall, the investment has led to a rapid increase in the number of academic publications and a change in academic culture, which is today more performance-oriented, research-focused and international (Shin 2009; Kim 2013; Park and Leydesdorff 2010; Kwon et al. 2012). As an indication of how rapidly Korean universities have developed: the 2013 Leiden Ranking of 500 universities now lists 18 Korean institutions (CWTS 2013). This is the same number as Japan, a neighboring country with comparable per capita income but whose population and economy are more than double the size of that of Korea.

In addition to growing research expenditure, other policy changes have also affected the knowledge production at Korean universities in recent years. These include the 2001 *Technology Transfer Promotion Law*, which encouraged universities to establish specific offices to promote transfer of technology to industry, and the 2003 *Law on Industrial Education and Industry-University Cooperation*, which encouraged universities to establish industry-university cooperation foundations to manage the intellectual property generated by university research (Eom and Lee 2010). Prior to the 2003 law, intellectual property had often been appropriated by the professors themselves (*ibid*). The growing emphasis on university research and technology transfer has also been matched by policies supporting the development of innovative SMEs (Eom and Lee 2010; Shapiro 2007; Sohn and Kennedy 2007).

In order to provide direction to these growing research and collaboration efforts, the Korea Institute for Science and Technology Planning (KISTEP) published a 10-year National Technology Roadmap (NRTM) in 2002. The NTRM provides technological foresight and contains consensus views among technology experts from industry, academia and government. These approaches have been replicated in specific areas of technology and constitute an additional tool for coordinating R&D investment by government, universities and industry since the mid-2000s (Park and Son 2006; Park et al. 2013).

3 KOREA'S TRIPLE HELIX DYNAMICS

This section focuses attention on the changes in Korea’s innovation system during the past decade and develops hypotheses on these changes as reflected in patent data. The main trend is that the role of government research institutions and large conglomerates continues to be strong, with SMEs and universities being strengthened to further support the development of Korea's national innovation system (Eom and Lee 2010; Sohn and Kennedy 2007; Lee and Park 2006; Lee 2013).

The growth in knowledge output is likely to be uneven across technology areas. Korea is already strong in some areas of technology, such as automotive, shipbuilding, railway systems, structural engineering, manufacturing systems and information and communication technology (ICT), and aims to further develop sectors such as nanotechnology, biotechnology, medical technology, environmental technology and aerospace (Park and Son 2006; Park et al. 2013). Therefore, in our analysis of the Korean knowledge production system, it is possible to distinguish between areas of technology based on their strength (i.e. share in knowledge production) and their growth (i.e. change in share of knowledge production). Based on patenting data (for methodological details, see section 5.3) "strong" technologies in Korea include: telecommunications, other consumer goods, and micro-structural and nano-technology. "Weak" technologies in Korea include: medical technology, measurement and mechanical elements. Fast-growing technologies also include micro-structural and nano-technology, and telecommunications, as well as materials and metallurgy. Among the slow-growing technologies are engines, pumps and turbines, and thermal processes and apparatus.

As university and SME participation in knowledge production is being encouraged, and Korea's government is promoting the development of new industries, the share of SME and university patenting and patent co-assignment is expected to increase (Kwon 2011). SMEs and universities are also expected to play a larger role in fast-growing technologies compared to slow-growing technologies, following the experience in advanced economies (e.g. Acs and Audretsch 1991; Anselin et al. 1997; Jaffe et al. 1993). In addition, due to legal changes which encourage the institutional appropriation of intellectual property, including the 2003 *Law on Industrial Education and Industry-University Cooperation*, we expect the number of individuals who are assigned patents to decline in favor of patent assignments to their employers, especially universities. In Japan, which passed similar legislation, this has been found to be the case (Motohashi and Muramatsu 2012). Given the previous policy lines, we propose the following hypotheses below, divided into general ones (H1 to H3) and ones focusing on fast-growing technologies (H4 and H5).

H1 The share in total patents and patent co-assignment by *universities* increases in the years 2001 to 2010.

H2 The share in total patents and patent co-assignment by *SMEs* increases in the years 2001 to 2010.

H3 The share in total patents and patent co-assignment by *individuals* declines in the years 2001 to 2010.

H4 There is a positive correlation between growth of total patents and patent co-assignment by *University* and growth of fast-growing technologies.

H5 There is a positive correlation between growth of total patents and patent co-assignment by *Industry* (*SMEs)* and growth of fast-growing technologies.

Having considered knowledge production among SMEs, universities and individuals we now consider knowledge production among conglomerates and government research institutes (GRIs). Given the dominant role of conglomerates in the national innovation system, it is likely that these tend to patent more in areas of technology in which Korea is already strong. However conglomerates may be less nimble and therefore patent less in fast-growing areas of technology, as suggested by Acs and Audretsch (1991). Therefore, concerning Conglomerates, we hypothesize:

H6 There is a positive correlation between growth in total patents and patent co-assignment by *Conglomerates* and growth of relatively strong technologies.

H7 There is no correlation between growth in total patents and patent co-assignment by *Conglomerates* and growth of relatively fast-growing technologies.

Because government policy is in part aimed at creating a more balanced innovation system we hypothesize that GRIs and universities, who depend on government funding to finance their R&D, are likely to patent more in areas of technology in which Korea is relatively weak and less in relatively strong technologies. Therefore:

H8 There is no correlation between growth in total patents and patent co-assignment by *Government* and growth in relatively strong technologies.

Finally, we will also consider specific linkages within the innovation system. Patent co-assignment is usually the result of risk-sharing and/or grasping opportunities from synergy in which two or more institutions invest their resources and, as a consequence, gain partial ownership of the intellectual property that is produced. Research collaboration with GRIs and universities seems more prevalent among conglomerates (Eom and Lee 2010), eventually in technology in which Korea is relatively weak due to the need to share knowledge resources. We also take co-assignment relations involving individual persons into account, as we assume that individuals prefer to collaborate with SMEs and universities. However, both for conglomerates and individuals, we have no (theoretical) indication on differences between technology sectors, reason why we present no hypotheses here.

4 PATENT DATA AND METHODOLOGY

4.1 Introduction

Patents are a form of intellectual property which grants holders the exclusive economic rights to an invention for a limited amount of time, this in exchange for its detailed public disclosure. Because of this public disclosure, patents form an excellent source for long-term bibliographic analysis for studies of newly created technology. Furthermore, national patent systems are to a large extent harmonized due to the 1970 Patent Cooperation Treaty (PCT) and the 1994 Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) adopted by the 159 member states of the World Trade Organization (WTO).

Though patents are widely used as an indicator for knowledge production or innovation activity, they can be problematic in causing bias because patenting propensities vary across firms and industries, with smaller firms and low-technology industry tending to patent less relative to their R&D expenditure (Kleinknecht et al. 2002). Thus, patents are best compared at the industry-level. In addition, the quality of patents can be highly variable, with some patents representing only incremental technological improvements and others representing radical innovations (*ibid*). Despite these disadvantages, we present an analysis here based on patents because they allow long-term and cross-country analysis and are indicative of the creation of practical knowledge and its potential application in industry.

Academic papers are also widely used in measuring size of knowledge production and research, but they have different functions in the knowledge production system. While publications encourage the sharing of new knowledge among a wider audience, patents provide explicit legal protection of the knowledge that is revealed in them. Academic papers do not provide this protection, but instead allow the authors to be recognized by the wider academic community, bestowing status upon them and the institutions with whom they are affiliated. Different strategies in these matters among academics and large companies, alongside the shorter timelines in research among companies compared to universities, tend to hamper collaboration between them in North America and Europe, but the barriers may decrease in importance (Bjerregaard 2010; Bruneel et al. 2010).

With regard to research collaboration, co-authorship of scientific documents such as patents and academic papers is widely considered to be an important indicator (Bukova 2010; Liao and Yen 2012). Co-authorship data of scientific documents has been widely used to map research networks (Grossman 2002; Hou et al. 2008; Wagner and Leydesdorff, 2005; Newman 2004, Lai et al. 2010), and has been validated as a proxy of the dynamics of research relationships (Wagner 2008).

However, co-authorship data does not capture all research collaboration (Malecki 2010) and not all co-authorship is accompanied by significant research collaboration. Other factors – political, personal or financial – can also play a role in forging co-authorship relations (Bukova 2010). Nevertheless, the dynamism of co-authorship relationships, especially between different actors – university, industry, government (UIG) - are considered to be indicative of the overall collaborative relationships that exist between them (Etzkowitz and Brisolla 1999; Leydesdorff 2003; Leydesdorff & Fritsch 2006; Leydesdorff et al. 2006; Park et al. 2005; Shapiro 2007).

With specific reference to patent co-authorship or co-assignment in Korea, Shapiro (2007) notes that Korean universities tend to file patents *independently*, after the collaboration projects have finished, and therefore often no patent co-authorship takes place. Nevertheless, patent data is widely used as an indicator of technological activity because it is a continuous data series that covers many industries and is therefore suitable for analyzing long-term cross-sector trends in science and technology (Kleinknecht et al. 2002; Hu and Mathews 2005; Griliches 1998; Lei et al 2012).

4.2 Patent data and methodology in this study

The patent data for the current research was downloaded from the website of the Korea Intellectual Property Rights Information Service (KIPRIS), http://www.kipris.or.kr. The assignee's information was obtained for all registered (approved) patents filed with the Korean Intellectual Property Office (KIPO) between 1 January 2001 and 31 December 2010. Because the patent registration process can take months and sometimes years, 2001-2010 is the most recent decade-long period for which complete data are available. In total, assignee data for 726,455 patents were downloaded.

Using only patents registered with the KIPO has some advantages and disadvantages. The KIPO has the most complete collection of Korean patents, with 506,832 patents registered between 2001 and 2010. This compares to just 57,200 registered in the PCT database maintained by the World Intellectual Property Organization (WIPO), which contains all patents registered in more than one country using the provisions of the PCT. The United States Patents and Trademarks Office (USPTO) holds the second-largest repository of Korean patents for the 2001-2010 period, listing 60,223 registered patents. Barriers for Korean inventors to patent at the KIPO are lower because the Korean language can be used, and patent application fees are lower for domestic applications. As the purpose of this study is a comprehensive overview of Korean knowledge producers and co-patenting relationships, KIPO patents are used. However for the purposes of providing an international comparison, PCT patent data is relied upon, as is also the practice at the OECD and the WIPO. During the period being studied a total of 1,402,182 PCT patents were registered.

The registered patent assignee information includes the assignee's name and an excerpt of their address identifying the assignee's province, city and district. For foreign assignees, the country is also included. Based on this information it is possible to classify patents based on assignee location and assignee type.

The Triple-Helix model traditionally distinguishes between three types of actors: *Government*, *University* and *Industry*. For the purpose of this study *Industry* is taken as legally registered for-profit entities whose status is clear from their official name: e.g. the equivalent of "Limited", "Ltd.", "Partnership", etc. (see Table 1), but excluding conglomerates and their subsidiaries. Accordingly, Industry is used in this study a proxy for small and medium-sized enterprises, although we realize that a few larger companies are included.

In this study two further categories are introduced: *Person* and *Conglomerate*. In 2010 Korean individuals gained ownership of 35% of all Korean patents assigned to Korean residents. This is a larger share than in other countries: United States individuals only owned 11% of patents assigned to United States residents in 2010. Thus, a large group of independent inventors appears to be a distinguishing feature of the Korean patenting system. The dominant role of R&D by large conglomerates is the other distinguishing feature of this system: in 2004 the nation's five largest firms accounted for 40.4% of R&D expenditure (Hemmert 2007). The *Conglomerate* category is based on the list of conglomerates and their subsidiaries published by the Fair Trade Commission (FTC), an agency of the Korean government. The FTC's 2001-2010 conglomerate lists contain 2,178 unique affiliated company names divided over 56 conglomerates. A distinction is also made based on assignee locations. All assignees with a Korean address are classified as *Korean*, all others as *Foreign*. 24.9% of assignees were classified as *Foreign*. An approach of splitting out private sector knowledge producers into different sub-sectors was also used by Lei et al (2012).

The classification is an automated process using Macros with the commercial spreadsheet software Microsoft Excel. The Macros split the assignee data string into multiple assignees (if applicable) and automatically searches the data and classifies the assignees when it matches certain text identifiers. An overview of the text used to identify and classify assignees is given in Table 1. The classification occurs in two rounds: in the first round the distinction between *Korean* and *Foreign* is made. In the second round the type of assignee is identified. Some classifications such as *Industry* and *Conglomerate* or *Government* and *University* face double identifications due to overlapping text identifiers. When this occurs, *Conglomerate* and *University* are the categories that are assigned. For example: "Samsung Electronics Co. Ltd." is identified as *Industry* by virtue of "Co. Ltd." and as *Conglomerate* because "Samsung Electronics Co. Ltd." appears on the FTC list. *Persons* are all applicants identified as *Korean* but not otherwise classified in one of the four categories.

Classification Categories	**Identifiers (Korean)**	**Identifier Equivalents (English)**
Government (and non-profit)	(사), 사단, (재), 재단, 연구회, 연구원, 평가원, 기술원, 관리원, 공단, 진흥협회, 대한민국, 조합, 의료원, 기술센터, 본부, 사회, 협회, 병원	Foundation, Association, Institute, Organization, Republic of Korea, Co-Operative, Ministry, Hospital, Etc.
University	학교법인, 과학기술원, 대학교, 대학, 학원	University, College, Institute of Science and Technology
Industry	(주), ㈜, 주식회사, (유), 유한회사, (합), 합자회사, (명), 합명회사, 한국지점,	Company, Inc., LLC, Corp., Co., Partnership, LLP, Bank, Etc.

	은행, [주], 공사	
Conglomerate	삼성전자, 현대중공업, 엘지전자, …	Samsung Electronics, Hyundai Heavy Industries, LG Electronics, etc.
Korean	서울, 부산, 충남, 충청, …	Seoul, Busan, Chungnam, Chungcheong, etc.

Table 1 – Overview of Classification Identifiers

In the entire database, covering the years from 2001 through 2010, 13,073 unique assignees were identified. Of these assignees 115 were classified as *Conglomerate*, 5,221 as *Foreign*, 2,817 as *Industry*, 4,610 as *Person*, and 119 as *University*.

The automated classification method is subject to some minor errors. Manual checking suggests that the errors are less than 0.5%, which is deemed to be acceptable, considering the size of the data set. Based on these errors, like the use of unusual or commonly misspelled institutional suffixes, the classification Macro was manually fine-tuned several times to improve the identification system. The errors were usually classified as *Persons*, and since Korean names tend to have only two or three characters, names of four or more characters usually signaled an error which was then investigated.

After completing the classification, a database was constructed using the commercial database software Microsoft Access. The database allows cross-referencing based on patent registration year, assignee type and international patent classification (IPC) code. The IPC code is used to classify patents by technology field using the IPC8 Technology Concordance tables published by WIPO (2013).

To enable some international comparison, the online Organization for Economic Cooperation and Development (OECD) Patent Database is used, http://stats.oecd.org. This database lists the number of international patents that have been registered in more than one country under the PCT and classifies them by country of assignee and IPC code, among others. Because Korea is a PCT member, and the KIPO data uses the same IPC codes to classify patents, both databases are fully compatible.

5 RESULTS AND ANALYSIS

5.1 Patent Assignees

The dynamics of the Korean innovation system immediately becomes evident by observing the patenting trends of different assignees over the years from 2001 through 2010, see Figure 1. Most notable is the absolute decline of *Conglomerate* patenting after 2005, witness a fall from almost 30,000 patents per year in 2005 to 10,000 patents per year in 2010, and the steady growth in *Industry*, *Person* and *University* patenting during the entire period. To facilitate analysis, the 2001-2010 time period is subdivided into three periods: Period I (2001-2003, 3 years), Period II

(2004-2006, 3 years) and Period III (2007-2010, 4 years). The periods are chosen to capture the rise and fall of *Conglomerate* patenting (Table 2). It is particularly the last period (2007-2010) in which the share of Conglomerate in all patents declined from around half of all patents to 19%, altogether a drop in the share by 61%. Conversely, the data confirm a growing share of *University* and *Industry,* but also of the category *Person* in patent production, witness a growth over the entire period by 299%, 49% and 99% respectively, although in absolute terms *Industry* patenting grew faster. Patenting by *Industry* and *Person* exceeded patenting by *Conglomerate* after 2007 and 2008 respectively (Figure 1), suggesting that Korea has experienced a shift in terms of knowledge producers. The two largest categories today tend to be *Industry* and *Person*, perhaps suggesting that *Conglomerate* makes increasingly use of technology outsourcing to innovative suppliers, most of which are likely to be SMEs, as is the case for component suppliers in many high technology industries (see, e.g., Acs and Audretsch 1991). Another possible reason for the decline in *Conglomerate* patent filings in Korea is the trend of applying for patents in foreign countries. For example, in 2010 Korean inventors filed 1,051 patents directly with the USPTO, up from 604 in 2001. Although a 447-patent/74% increase, it pales in comparison to the 41,473-patent/197% increase in patents filed by Korean inventors at the KIPO between 2001 and 2010.

The data also show a rise in *Person* patenting, both in absolute and relative terms, which goes against the expectation of increasing institutionalization of research and the correspondent expected decline in patent assignments to individuals. Because of its size and growth, the role of individuals' patenting behavior introduces an interesting dimension into Korea's national innovation system. It may be an indication of the leverage that individual researchers have relative to the organizations that employ them because they are able to retain ownership of the intellectual property they produce. It is possible that that the rising *Person* patenting is related to *Industry* and *University* patenting, which have also sharply increased.

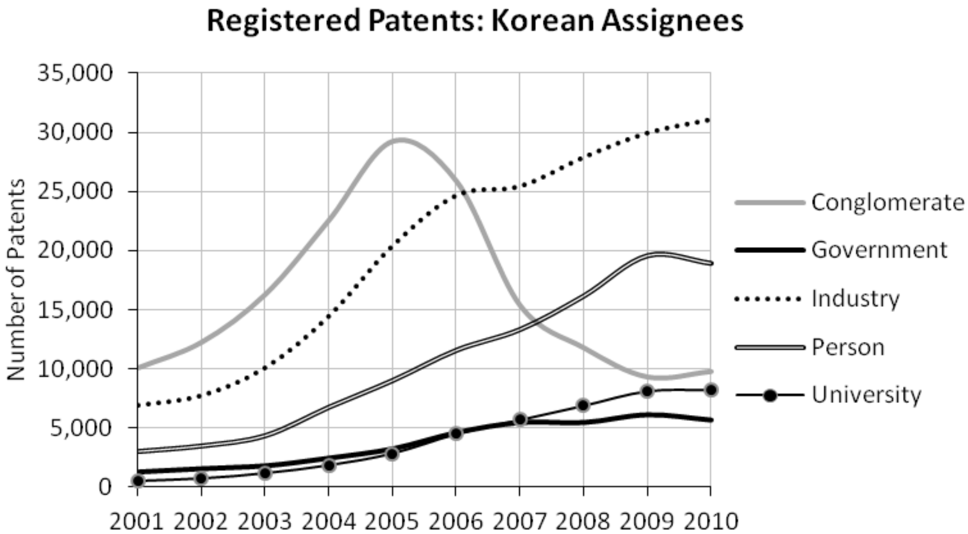

Figure 1 - Registered Patents by Korean Assignees, 2001-2010

Assignee Categories	Period I (2001-2003)	Period II (2004-2006)	Period III (2007-2010)	Change in Share from Period I to III
Conglomerate	49.0%	51.3%	19.2%	-61%
Government	6.1%	6.6%	9.3%	+52%
Industry	31.5%	38.3%	47.0%	+49%
Person	14.0%	17.7%	28.0%	+99%
University	3.0%	5.8%	11.9%	+299%
Total:	100%	100%	100%	0%

Table 2 - Share and Changes in Share of Patent Assignments by Assignee Category

Regarding co-assignment (co-patenting), we may observe the following trends (Figure 2). *Industry* and *University*, the two categories assumed to grow, developed differently, with co-patenting increasing in *Industry* but declining in *University*. The latter may be explained by an increased patenting at university after completion of collaborative projects (Shapiro 2007), and/or research agreements that give the commercial fund-providers (e.g. *Industry* and *Conglomerate*) the first right to patent, rather than co-patenting. Note that there was a sharp decline of co-patenting in *Government*. By contrast, the category *Person* remained broadly at the same high level, namely, a share of co-patenting of 40%. In addition, the overall decline in patenting among *Conglomerate* tended to go along with an increased share of co-patenting in the the 3rd period, roughly from 5% to 15% of all patents.

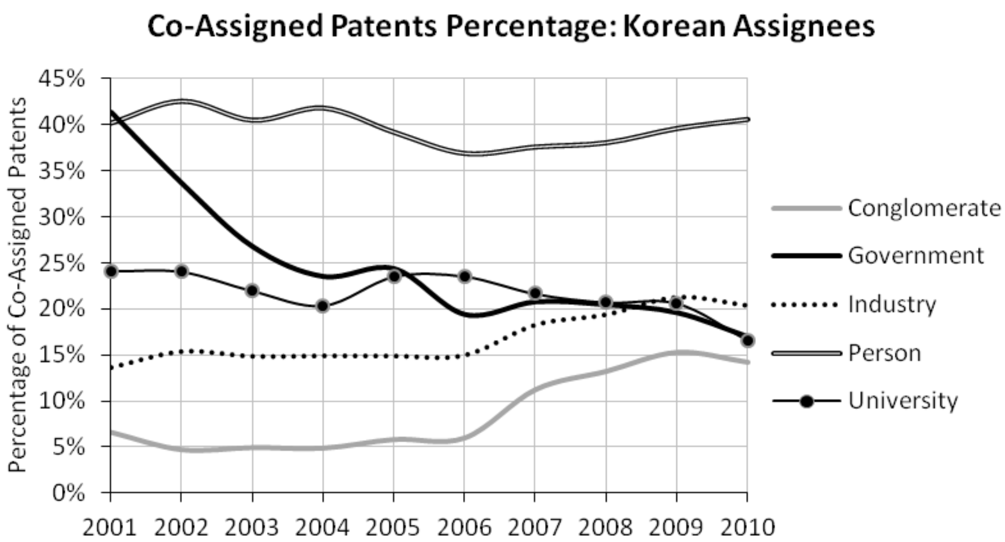

Figure 2 - Co-Assigned Patents Percentage (of Total Patents) by Korean Assignees, 2001-2010

For our hypotheses, dealing with *University*, *Industry* (SMEs) and *Person* for which we expected large changes, the above trends mean the following. Hypohesis 1 formulated on the assumption of both growth in patenting and co-patenting in *University*, due to their extended research tasks, can be confirmed with regard to growth in overall patenting but needs to be rejected with regard to co-patenting. By contrast, Hypothesis 2 on *Industry* can be confirmed with regard to both overall patenting and co-patenting. Hypothesis 3, which deals with the category *Person*, can be rejected for the two parts of the hypothesis, as overall patenting increased while co-patenting remained broadly at the same, relatively high level.

5.2 A Focus on Collaboration Partners

With regard to patent collaboration, the following trends have emerged (Table 3). Among the partners with whom *Conglomerate* has increased co-patenting, *University* has grown strongest (by 37%) and *Industry* has grown modestly (by 7%), albeit from a higher initial level, witness an initial share of 14% (period I). *Industry*, that equally increased co-patenting, did this mainly through partnering with *University*, witness an increase over the whole period by 214%, starting from a low initial level of 3% (period I). It is likely that the increase in R&D funding and quality has encouraged business-academic research collaboration, both for *Conglomerate* and *Industry*. These changes can be understood as an increased role of the university in Triple Helix formation in Korea, at the expense of co-patenting relationship with *Government*. In addition, the co-patenting relationship between *University* and *Government*, has also grown rapidly (by 263%) although from a low base (1.0% in period I). The previous results contrast with the findings of Kwon et al. (2012) who, based on scientific publication data, suggested that the relationship between Korean universities and their domestic partners has weakened.

Yet the *Industry-Person* co-patenting relationship tended to remain the most important co-patenting relationship throughout all three periods (Table 3), and has grown to a share of 41% of all co-patents in period III. Although it is not clear who the individual patent assignees are, the high co-patenting rate of the category *Person* is unique to *Industry* and could be part of a competitive strategy to attract and retain research staff by SMEs. It is also possible that some individual patent assignees are working for universities, which is plausible given the tradition of university researchers to retain ownership over patents (Kim 1997; Eom and Lee 2010), they could be an important channel for the exchange of knowledge between university and industry.

In conclusion, patent co-assignment data indicate that Korean universities are taking over the role of *Government* in R&D collaboration with businesses, while the role of individuals appears significant but remains unclear. The rise of Korean universities as pivots in collaboration with the business world, as suggested by the patent data, is a possible new development and supports the view that the research at universities is industry-relevant, as intended by the national policies. However this conclusion should be treated with caution: the 2001 and 2003 legislative changes may simply have encouraged patent assignment to universities without significant changes in real cooperation between universities and the business world.

Co-Assignment Relationship	**Period I** (2001-2003)	**Period II** (2004-2006)	**Period III** (2007-2010)	**Change** from Period I to III

Conglomerate-Industry	13.6%	23.6%	14.5%	7%
Conglomerate-Governmt.	21.0%	16.2%	5.7%	-73%
Conglomerate-Person	4.7%	3.7%	2.9%	-38%
Conglomerate-University	2.5%	6.7%	3.4%	37%
Industry-Government	12.0%	11.2%	7.0%	-41%
Industry-Person	27.1%	42.0%	40.7%	50%
Industry-University	3.3%	7.4%	10.5%	214%
Person-Government	2.4%	3.2%	2.4%	-1%
Person-University	4.5%	5.5%	3.3%	-27%
University-Government	1.0%	3.3%	3.7%	263%

Table 3 - Share and Changes in Share of Patent Co-Assignment Relationship (of Total Co-Assigned Patents)

5.3 Korea's International Performance in Technology

To gain insight into Korea's technological performance, namely with the aim to identify in which technologies Korea is "strong" or "weak", and which technologies grow quickly or slowly, it is useful to compare the country's patent output to that of other countries. Naturally, Korea cannot be the leader in all technologies, and therefore the country will be stronger in some areas of technology and weaker in others. There are also differences in the growth rate of technological output which can be captured by PCT patent data. Furthermore, using only the KIPO database for international patents is likely to provide a biased sample. Firms in certain industries choose to only apply for patents in large, strategic jurisdictions such as the European Union and the United States to save costs as this allows them to 'fight' potential violators in strategic export markets. At the same time, the pharmaceutical industry, for example, patents in a large number of jurisdictions to fight the production of generic drugs which can be produced on a smaller scale and are not exported (see, O'Connell 2012).

Based on PCT patent data, it is possible to distinguish technologies regarding Korea's relative strength or weakness, i.e. the share of Korean PCT patents in the world PCT patents, and increase/decrease in Korean share of PCT patents. A summary of the 34 technologies identified by WIPO[1], ranked according to growth is provided in Table 4 (Annex 1 provides the full table).

Ranking (Growth)	Technology	PCT Patents: Korean Total	PCT Patents: Korean %	Growth Rate 2001-3 to

[1] All patents in the OECD and KIPO databases are classified using the International Patent Classification (IPC) system, a globally harmonized system for assigning patented inventions to specific science and technology domains. There are currently 648 IPC domains which, by using the World Intellectual Property Organization's (WIPO) concordance tables, can be re-categorized into 34 fields of technology. By doing so one of the main problems with patent data is avoided: the varying propensities to patent between technology fields. By comparing the Korean share of PCT patents to the World amount (which in telecommunications is as high as 9.7%) also allows the propensity to patent and fluctuations in patent output to patent to be normalized. When major new discoveries are made there can be a temporary increase in patenting activity which, if not properly contextualized, can be mistaken for an increase in R&D expenditure or a rise in productivity, which may not be the case. Therefore patent output in any sector should be compared to the global average.

		2001-2003	2001-2010	2007-10
1	Micro-structural and nano-technology	5	8.5%	946%
2	Telecommunications	445	9.7%	251%
3	Materials, metallurgy	82	3.6%	223%
4	Measurement	189	2.0%	205%
5	Semiconductors	211	5.4%	183%
...	...	...	...	...
30	Furniture, games	315	6.1%	61%
31	Mechanical elements	118	1.8%	52%
32	Handling	186	2.8%	52%
33	Engines, pumps, turbines	153	2.5%	46%
34	Thermal processes and apparatus	176	6.1%	34%
	Average	N/A	**4.1%**	**138%**

Table 4 - PCT Patents: Korean Total (2001-2003), Korean Percentage of World Total (2001-2010) and Growth Rate of Korean Share between 2001-2003 and 2007-2010.

What is evident from the complete data summarized in Annex 1 is that Korea's PCT patenting profile is becoming less balanced: patenting has tended to grow most in technologies in which Korea already has significant strength, like micro-structural and nano-technology, and telecommunications, while growth is slower in weaker areas, like engines, pumps and turbines, and thermal processes and apparatus. This development is also reflected in a high correlation between Korea's PCT patent share and growth rate: 0.39, which is statistically significant at the 95% level. To some extent this trend is worrying, given Korean policy makers' desire to broaden the country's technology base, however it could also be a part of global trends towards increased technological specialization by countries.

5.4 Triple Helix Dynamics Across Technology Areas

In this section, we focus on changes in patenting behavior by the previously addressed five knowledge producers, *Conglomerate*, *Government, Industry, Person* and *University*, with regard to two sets of technology dimensions: technology strength and technology growth, both based on PCT patents (Table 5). Conceptually speaking, it offers a picture of the technology landscape, divided by 34 technology areas (subsectors), thereby allowing to identify the knowledge producers' emerging patenting behavior.

The relative international performance of Korea in technology areas, as reflected in the PCT patent data correlates to the patenting behavior of different main knowledge producers, such as *Conglomerate*, *University*, etc. in the same technology areas. Because 34 technology areas are available, it is possible to carry out a statistical analysis and draw general conclusions about triple helix dynamics across technology areas.

Table 5 presents the correlation between three metrics - growth in patents, in co-assigned patents and in patents from specific collaboration – and growth in the two technology dimensions – technology strength and technology growth - for Korea.

Pearson correlation coefficient is used with testing at the 90% confidence interval. Although this lower interval is used, many correlations are significant at the 99% confidence interval. We summarize the results based on statistical significance as follows:

- With regard to total patents, *Conglomerate* tends to patent more in technology areas in which Korea is strong, while *Government* and *University* tend to patent more in high-growth technologies. In addition, *Industry* (SMEs) tends to patent less in both sets of technology areas, while *Person* tends to patent less only in high-growth technologies.
- With regard to co-assigned patents, *Person* tends to collaborate more in high-growth technologies, while *Industry* tends to collaborate less in strong technologies and *University* tends to collaborate less in high-growth technologies.
- Regarding specific partnerships in patenting, *Conglomerate-Industry* and *University-Government* occur more often both in strong technology and high-growth technology areas. In addition, *Industry-Government* and *Industry-University* collaborate more strongly in high-growth technology areas.

Assignees and Relationships	**PCT Patents: Korean Percentage** (proxy for technology strength)		**Growth Rate (2001-03 to 2007-10)** (proxy for technology growth)	
	Pearson Corr.	90%-Significance	Pearson Corr.	90%-Significance
Total Patents				
Conglomerate	0.40	Yes	-0.14	-
Government	-0.15	-	0.54	Yes
Industry	-0.49	Yes	-0.41	Yes
Person	-0.14	-	-0.29	Yes
University	0.04	-	0.68	Yes
Co- Patents				
Conglomerate	-0.27	-	0.22	-
Government	-0.17	-	-0.20	-
Industry	-0.32	Yes	0.15	-
Person	-0.06	-	0.52	Yes
University	-0.11	-	-0.30	Yes
Co-Patent Relationships				
Conglomerate-Industry	0.08	-	-0.07	-
Conglomerate-Governmt	0.16	-	0.07	-
Conglomerate-Person	-0.22	-	-0.27	-
Conglomerate-University	0.48	Yes	0.60	Yes
Industry-Government	0.19	-	0.77	Yes
Industry-Person	-0.13	-	-0.24	-
Industry-University	-0.18	-	0.43	Yes
Person-Government	-0.23	-	-0.12	-
Person-University	-0.11	-	0.02	-
University-Government	0.33	Yes	0.48	Yes

Table 5 - Correlation between Triple Helix (Assignee Patenting and Co-Patenting Properties) and Strength and Growth of Technology Areas

The evaluation of Hypotheses 4 through 8 brings various interesting results to light on total patents and co-assigned patents. Concerning Hypothesis 4, although *University* patenting tends to be mostly in high-growth technologies, its co-patenting is primarily in low-growth technologies. This divergence suggests that universities follow a different collaboration strategy in the two technology groups. Perhaps related to the divergence in *University* collaboration pattern is *Person*, which displays the opposite pattern: *Person* tends to patent more in low-growth technologies while co-patenting more in high-growth technologies.

Hypothesis 5 concerning *Industry*, is rejected with regard to its two parts: *Industry* patenting and co-patenting appear to be concentrated in low-growth, weak technologies. Further, Hypothesis 6 on *Conglomerate* patenting, can be partly accepted: *Conglomerate* patenting is more often in strong technologies, but co-patenting does not, while Hypothesis 7 is fully accepted as *Conglomerate* patenting and co-patenting do not happen strongly in high-growth technologies. Hypothesis 8 is concerned with *Government* and involvement in strong technologies. The hypothesis can be confirmed as *Government* is not strongly involved in strong technology areas, not regarding all patents and not regarding co-assigned patents. *Government* tends to be more involved in fast-growing technology areas (all patents).

Overall, the pattern of *Government* and *University* patenting with its concentration in high-growth technologies is interesting, as it suggests that public R&D funding is a key factor in directing the national innovation system towards new, quickly growing, technologies. Likewise, it is interesting to note that the *Conglomerate-University* co-patenting relationship and the *Government-University* co-patenting relationship are both strongly involved in strong and high-growth technology areas. This suggests that the new role of universities is not only broadly supported by the government but also supported and materialized by the conglomerates.

6 CONCLUSION

This paper attempted to picture and better understand the dynamics in the Korean innovation system, in particularly its Triple Helix changes in the past decade. Trends were identified using patent data over the years 2001 through 2010 for various knowledge producers, particularly, against the background of the new national policies that have directed public investment toward university and SME research and have encouraged deeper university-industry collaboration. It is the first study, using a detailed database on patents, including amounts of patents by assignees, collaboration in patenting, and technology fields involved in patenting. The following research questions were addressed: (1) Which changes have taken place in relative strength of *knowledge producers* in Korea's innovation system in the past decade and which patterns of collaboration between them have emerged? (2) How do these changes differ between *technology fields* and what does this mean in terms of a more balanced development?

Public support for universities and SME-based R&D has increased during the decade starting in 2001 and has resulted in a grown patent output, though in different patterns, from a low initial level by universities and higher initial level for SMEs. Yet somewhat unexpectedly, patent output by conglomerates has first risen, and then fell back, while patenting by individuals has continued to increase to the extent that individuals accounted for nearly a third of Korean patent assignees in 2010. It is unlikely that the wave of conglomerate patenting has been the result of rapidly changing R&D expenditure: business R&D expenditure as a whole has risen steadily during the period from 2.47% of GDP to 3.74% of GDP in 2010. More likely is that organizational changes have occurred, either within conglomerates in terms of how they patent, or externally, in terms of the outsourcing of innovation to individuals and SMEs. Co-patenting data suggest that businesses, including conglomerates and to a strong degree SMEs - have increased collaboration with universities, while collaboration with government research institutes has decreased. This development points to an emerging success in strengthening the position of universities.

In general, Korean scientific output has grown most rapidly in areas of technology where Korea already has significant strengths, indicating a less-balanced development in terms of *technology areas*. In high-growth technologies, universities and government research institutes tend to patent more, while conglomerates tend to patent more in strong technology areas. SMEs' patenting is the opposite of patenting by conglomerates, with the last patenting more in low-growth, weaker technologies. As business-university co-patenting and university patenting mainly occur in high-growth technologies, universities appear to be making a significant contribution to the development of Korea's technology-intensive industries. From this point of view, the transition from the "double helix" of GRI-conglomerate relations towards a more balanced innovation system in terms of *knowledge* producers, in which university and SME research play a significant role, appears to be well underway. These shifts may also be a sign of social changes which tend to accompany and reinforce social changes (Phillips 2014).

Despite the interesting results we have also encountered some drawbacks in the analysis, which could be addressed in future research. These are mainly connected with the method of using patents, as follows: (1) it is unclear how the picture of the Korean knowledge production derived from the patent data compares to other countries, (2) patent quality is not evaluated, and thus the quantitative patent picture could be supplemented by qualitative indicators, and (3) non-Korean patenting and co-patenting could be more fully included in the analysis to complete the picture. And to complete the picture in terms of innovation, further innovation output indicators could be taken into account, including linking of patents and academic publications, following the example by Gautam et al. (2014).

The results also raise a number of further research questions about Korean knowledge production, including the wave of patenting by conglomerates which peaked in 2005, and the unusually large share of individual patent assignees and the institutions with which these persons are affiliated. Also, research could be devoted to the trend that Korea, internationally, gets stronger in technologies in which the country is already strong, thus preventing the desired broadening of the technology base.

Acknowledgements
The authors wish to thank the session chair and audience during the Daegu-Gyeongbuk International Social Network Conference (DISC) 2013 for their valuable comments on a presentation that preceded this paper.

Annex 1: Complete version of Table 4, PCT Patent Statistics

Ranking (Growth)	Technology	PCT Patents: Korean Total 2001-2003	PCT Patents: Korean % 2001-2010	Growth Rate 2001-3 to 2007-10
1	Micro-structural and nano-technology	5	8.5%	946%
2	Telecommunications	445	9.7%	251%
3	Materials, metallurgy	82	3.6%	223%
4	Measurement	189	2.0%	205%
5	Semiconductors	211	5.4%	183%
6	Basic materials chemistry	102	2.4%	172%
7	IT methods for management	182	6.7%	156%
8	Surface technology, coating	82	2.5%	147%
9	Biotechnology	293	3.2%	141%
10	Machine tools	99	2.6%	135%
11	Basic communication processes	51	2.6%	128%
12	Pharmaceuticals	410	2.6%	127%
13	Chemical engineering	154	2.7%	126%
14	Computer technology	422	4.0%	123%
15	Digital communication	449	5.8%	119%
16	Other special machines	164	2.9%	108%
17	Other consumer goods	323	9.1%	107%
18	Textile and paper machines	91	2.3%	107%
19	Transport	182	2.5%	105%
20	Civil engineering	198	4.0%	100%
21	Medical technology	321	2.1%	98%
22	Food chemistry	83	3.6%	97%
23	Audio-visual technology	753	8.0%	91%
24	Electric machinery, apparatus, energy	403	4.3%	84%
25	Organic fine chemistry	259	2.6%	83%
26	Control	110	2.7%	77%
27	Optics	332	4.5%	73%
28	Macromolecular chemistry, polymers	173	3.3%	69%
29	Environmental technology	85	4.2%	66%
30	Furniture, games	315	6.1%	61%
31	Mechanical elements	118	1.8%	52%
32	Handling	186	2.8%	52%

33	Engines, pumps, turbines	153	2.5%	46%
34	Thermal processes and apparatus	176	6.1%	34%
	Average	N/A	**4.1%**	**138%**

Table 6 - PCT Patents: Korean Total (2001-2003), Korean Percentage of World Total (2001-2010) and Growth Rate of Korean Share between 2001-2003 and 2007-2010.

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