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Academic entrepreneurship: exploring the effects of academic patenting activity on publication and collaboration among heterogeneous researchers in South Korea

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Abstract
This paper examines the effects of academic patenting activity on academic publication and on collaboration between researchers in academia and researchers in industry or public research institutes. The study focuses on the case of South Korea, where university research rapidly evolved along with economic development, and where university–industry linkages are strongly encouraged by government policies. The study collected data on 632 full-time faculty members in the natural sciences, bio sciences, and engineering sciences at 46 Korean universities from the National Research Foundation of Korea and other statistical data sources. The results show that academic patenting complements publishing up to a certain level of patenting activity, but then replaces publishing. Academic patenting also is shown to have positive effects on research collaboration with industry and statistically non-significant effects on research collaboration with researchers at public research institutes. This study expands the analysis on the effects of patents on research collaboration among heterogeneous researchers as well as publications in South Korea.

Keywords University–industry linkage · Patent · Publication · Research collaboration · South Korea

1 Introduction

While university–industry linkages have become an important factor in today's knowledge network society, the identity of universities seems to have undergone a change as universities have shifted from being part of the public sphere to becoming a site for fostering entrepreneurial attributes (Slaughter and Rhoades 2004). Universities pay more attention to recruiting students, securing external funding, and gaining higher status through fierce competition with other universities and research institutes

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(Newman et al. 2004; Shin and Harman 2009). Universities now aggressively try to commercialize their research by applying for patents and copyrights. In addition, government policies such as the Bayh–Dole Act in the United States and similar policies in other countries have become common (Buenstorf 2009; Mowery et al. 2001). The development of new networks within the private and public sectors is related to globalization, and entrepreneurial activities are no longer confined to the sciences and engineering, but are found in every academic area (Slaughter and Rhoades 2004).

A substantial literature regarding these concerns has emerged since the late 1990s. Etzkowitz et al. (2000) analyzed the shift towards the emergence of an ‘entrepreneurial university’, which they have explained as a response to the increasing importance of knowledge in national innovation systems. On the other hand, some scholars regard such changes as a threat to the identity of the university (Bok 2003; Slaughter and Leslie 1997). As the discourse on the entrepreneurial paradigm around higher education systems has intensified, contemporary universities and the academic profession have shown an ambivalent attitude towards university–industry relations, and may seek to re-establish their identity by exploiting the tension between traditional norms and entrepreneurialism (Hackett 2005; Henkel 2005). In addition, the effects of the entrepreneurial paradigm on university research are still a gray zone. It is therefore important to study the effects of the institutionalization of university–industry linkages as a main regime of entrepreneurialism in universities, while there is a need for a comprehensive and in-depth exploration based on empirical data.

This study focuses on the South Korean context, where university research rapidly evolved along with the country’s economic development. A close relationship between university research and industrial development was strongly encouraged by government policies that considered research the engine of economic development. As a result, universities in South Korea (hereafter, Korea) often focus on applied and development research. However, the rate of R&D expenditures on basic research has decreased from 78.0% in 1989 to 42.4% in 2000 and then to 40.0% in 2012 (Ministry of Science and KISTEP 1989–2012). On the other hand, the number of patents applied for by universities has increased; the number of academic patent applications exceeded the number from public research institutes in 2007 (Korean Intellectual Property Office 2010). Korean four-year universities received 37,873 patents in 2012, and the average increase in the annual rate of academic patents during 2008–2012 was 23.4% for domestic patents and 22.0% for international patents (Ministry of Education and National Research Foundation of Korea 2012).

Despite the significant development of academic entrepreneurial activities in Korean universities, the country’s institutionalization of university–industry linkages and its effects on university research have not been fully explained. Some previous empirical studies have analyzed the outcomes of university–industry cooperation and examined the factors that influence university–industry linkages (Han and Kwon 2009; Kim and Lee 2007; So and Yang 2009). Others have investigated the evolutionary patterns of knowledge production and research universities in Korea (Choung and Hwang 2013; Shin and Lee 2015). However, few studies have examined the historical evolution of university–industry linkages in Korean academia and its effects on university research and research collaboration. Taking academic patenting activity to represent the institutionalization of university–industry linkages, this study analyzes its effects on publication activity and research collaboration between researchers in academia, industry, and public research institutes.

2 Literature review

2.1 Institutionalization of University–Industry linkages in Korea

Korean research and development (R&D) systems were cultivated as part of the country's economic development plans, and the Korean government began establishing public research institutes such as the Korea Institute of Science and Technology (KIST) to support industrial development in 1966 (Shin and Lee 2015). KIST focused on importing technologies from abroad and transferring them to industry, operating as a think-tank of the national science and technology sectors. During the late 1960s and early 1970s, a comprehensive legal foundation was established with legislation such as the Science and Technology Promotion Act of 1967, and the Ministry of Science and Technology was established as a special government body to coordinate matters of science and technology. In addition, in the 1970s, five major public research institutes—the Korea Nuclear Energy Research Institute, the Korea Industry Standard Research Institute, the Korea Mechanical Research Institute, the Korea Chemical Research Institute, and the Korea Communication Technology Research Institute—were launched, along with the Daeduk Research Complex, a pioneering research institute network. Government support for university research was relatively less developed in the 1970s, and the role of the university was limited to teaching and training industrial labor while the public research institutes acted as the main agents to conduct research and support economic development.

In the 1980s, the Korean government began to encourage private companies to establish in-house research centers to meet their technological demands. As a result, the number of in-house research centers increased from 53 in 1981 to 183 in 1985, and to 1000 in 1991 (Ministry of Science and Technology 2008). Big companies such as Samsung, Hyundai, and LG competitively established their own research centers, which became crucial actors in national research development. At the same time, Korean higher education expanded rapidly from 403,000 students enrolled at four-year universities in 1980 to 1,040,000 students in 1990 (Shin and Lee 2015). The Ministry of Education established the Korea Research Foundation in 1986, beginning in earnest to support university research. For example, R&D expenditure by public sources for university research dramatically increased from 25,871 million won in 1983 to 76,082 million won in 1990, and 375 university research centers were established by 1990 (Ministry of Science and Technology 2008).

In the 1990s, the Korean government began to push universities' research function as a vehicle for knowledge transfer to aid regional and national development. The Korea Research Foundation commenced the Center for Research Excellence Development Project in 1990 to build a group of leading scientists and to facilitate university–industry research cooperation. The Scientific Research Center (SRC) and the Engineering Research Center (ERC) were established in universities by this project. In 1995, the Regional Collaborative Research Center (RRC) was introduced to link regional universities to industrial technological demands. The Korean government also established techno and science parks that integrates R&D resources of university-industry research cooperation (Kim et al. 2000). Korean universities' research programs thus developed in response to strong government-driven polices focused on restructuring the university system. One of the main policies is Brain Korea 21 (BK 21), which was launched in 1999. The BK 21 project changed the research scene and enhanced the graduate programs of Korean universities by providing fellowship funding for graduate students, postdoctoral fellows, and contract-based academics (Shin 2009a; Shin and Lee 2015). As universities' research capacities increased, public research institutes, corporate research centers and universities came together to form a university–industry cooperation system. In particular, legislation related to university–industry cooperation was reformed in 2003, after which the universities had an established legal foundation for commercialization of academic knowledge and university–industry cooperation. The Industry–Academic Cooperation Foundation operates within universities as an independent corporate body to support external and internal activities of university–industry linkages such as patenting, spin-offs, external research fund management, and so on. In addition, government funds now support university ownership of patents. In the 2000s, the Korean government tried to displace the government-driven policies for university–industry cooperation with initiatives to develop a new system based on collaborative networks between academia, industry and government. As part of these initiatives, the University Promotion Project Focused on University–Industry Cooperation was introduced to facilitate a university-led industrial–academic cooperation system during 2004–2013, and the New University for Regional Innovation (NURI) project was launched to support the network between regional universities, research institutes, companies, and local government during 2004–2008. In 2012, the Leaders in Industry–University Cooperation (LINC) project was introduced as a comprehensive merger of three earlier projects: the University Promotion Project Focused on University–Industry Cooperation, the NURI project, and the Leading Project for the Broad Economic Region. The goals of LINC are to facilitate the specialization of university programs, to enhance field-oriented education, to assist employment of graduates, to provide business venture training, to alleviate mismatching between university education and job markets, and to lead regional industry development (Ministry of Education, Science, and Technology 2012). Fifty-one universities were selected to take part in the LINC project, and 170 billion won was invested in it. Furthermore, the Program for Industrial needs-Matched Education (PRIME) was initiated in 2016 to adjust the mismatching between university education and job markets, and to enhance the quality of university education.

At the same time that Korean universities have been developing their research function, they have been increasing their entrepreneurial activities such as patenting. Since 2004, once university ownership of patents began to be supported by government funding, the number of patent applications by 46 Korean universities, having relatively strong research performance among total four-year universities (Shin 2009b), increased dramatically from 518 in 2000 to 1624 in 2004, and then to 8215 in 2009. On the other hand, research collaboration between researchers at universities and at industrial and public research institutes (hereafter, 'UIG coauthored publications') has been less active. Lee (2015) presented that ratio of UIG coauthored publications among total SCI publications in these 46 Korean universities grew from 15.15% in 2000 to 17.67% in 2009. There is a question whether active and aggressive academic patenting activities practically enhance knowledge and technology transfer and research collaboration between various researchers. Korean academic case might be an interesting example to analyze the effects of academic patenting on research publication and collaboration among researchers in academia, industry, and public research institutes.

2.2 Research commercialization and multiple channels for academic knowledge transfer

The idea that universities have a research function was originally introduced by Humboldt (Berglar 1970; Leavis 1943). The role of university research continued to grow more important as the university became a multi-functional organization that combines teaching, research, and social service functions (Kerr 1995). With the growing social interest in university research and its socio-economic implications, universities began to be directly involved in social development, and with the rise of neoliberalism, they began to pay more attention to their relationship with markets and entrepreneurial activities. With the growing emphasis on networks between academia, industry, government and society, many studies and discussions of the relationship between higher education and society have appeared, spearheaded by Etzkowitz (1983), who suggested the concept of 'entrepreneurial university', and Clark (1986), who presented a triangle model to examine the dynamic relationship between the state, the market and the academic profession, and Slaughter and Leslie (1997), who discussed the effects of capitalism on higher education.

Moving beyond their traditional teaching and academic research activities, universities now engage in various research commercialization activities such as patenting, licensing, and running spin-offs. While research commercialization has become a main instrument for academic research to contribute to economic development, there are multiple channels through which university research is transferred to society (Perkmann et al. 2013; Salter and Martin 2001).

For example, Cohen et al. (2002) presented various channels for university knowledge transfer including publications and reports, attendance at meetings and conferences, personnel exchanges, patents, licenses, contract research, consultancy work, spin-offs, joint ventures, and so on. They also suggested that the key channels through which university research impacts industrial research are published papers and reports, public conferences and meetings, informal information exchange, and consulting. On the other hand, Meyer-Krahmer and Schmoch (1998) surveyed German university researchers, and found that collaborative research and informal contacts are important channels. Some other previous studies have described personnel exchanges or the hiring of graduates as effective methods of knowledge transfer (Guebeli and Doloreux 2005; Meyer-Krahmer and Schmoch 1998; Zucker et al. 2002). In addition, Bekkers and Freitas (2008) suggested the relative importance of multiple channels of academic knowledge transfer according to different contexts such as disciplinary origin, the characteristics of researchers, and the environment in which the knowledge is produced and used. Etzkowitz and Leydesdorff (1997) proposed the triple-helix model that collaborative knowledge production based on the relationship among university-industry-government has been more crucial to produce the knowledge useful in society and to understand the context of capitalization of knowledge.

While a fair amount of research has thus explored the importance of university–industry linkages and various knowledge transfer channels between universities and industry, few studies have focused on the interrelationships between multiple academic knowledge transfer activities (Nelson 2012), and the effects of academic research commercialization on academic research activities and research collaboration (Crespi et al. 2011). Along with addressing these topics, the present study focuses on important knowledge transfer activities suggested by previous literature (Cohen et al. 2002; Meyer-Krahmer and Schmoch 1998), and aims to analyze the effects of academic patenting activity on channels for academic knowledge transfer to other parts of society beyond industry. This study highlights three main knowledge transfer channels between university, industry and public research institutes: academic patents, journal publications, and research collaboration. Academic patents are one of the main instruments for technology transfer, and are treated as a proxy variable for academic research commercialization and the institutionalization of university–industry linkages (Perkmann et al. 2015; Wong and Singh 2013). Academics share their knowledge and technology with the scholastic community through publishing their research and collaborating with peers. Academic literature such as journal publications and books is thus a main channel of academic knowledge transfer (Cohen et al. 2002; Narin et al. 1997). Research collaboration is also a crucial mechanism for knowledge transfer through cognitive interaction between researchers (Heinze and Kuhlmann 2008; Shin et al. 2013; Tijssen 2012). Academic research collaboration takes various local and global forms, depending on actors and purposes, ranging from collaboration between individual scholars, apprenticeships between professors and students, and collaboration between disciplines or institutions, to collaboration between sectors such as academia, industry and public research institutes. The specific interests of this study include how the capitalization of knowledge has led to dynamic modes of knowledge production, and is growing research collaboration among university–industry–public research institutes beyond the ivory tower (Etzkowitz and Leydesdorff 1997; Gibbons et al. 1994). This study therefore pays attention to research collaboration between heterogeneous researchers like university–industry and university–public research institute collaboration, as well as to research publishing and academics' patenting activities as knowledge transfer channels.

2.3 Relationships between academic patents, publications, and collaboration

While studies on the relations between academic patent activities and publications have proliferated, they present contradictory results (Crespi et al. 2011). Some studies suggest a complementary relation between academic patents and publications (Azoulay et al. 2007; Breschi et al. 2008; Gans et al. 2017; Grimm and Jaenicke 2015; Park et al. 2008; Thursby and Thursby 2004), while others claim that patents tend to substitute for publications (Agrawal and Henderson 2002; Calderini et al. 2009; Murray and Stern 2007). In addition, some studies analyzed the time delay between scientific research and technology patents (Finardi 2011; Zhang et al. 2017).

Azoulay et al. (2007) explored the individual, contextual, and institutional determinants of faculty patenting behavior in a panel dataset of 3862 academic life scientists in the United States. They report that patent volume predicts the amount of publications, and they claim that patenting behavior is a function of scientific opportunities. Thursby and Thursby (2004) also showed that the involvement of faculty in university licensing and development of inventions is positively associated with publication. Grimm and Jaenicke (2015) examined the relationship between patenting and publishing in Germany, and they concluded that there is a positive feedback relationship between them. Breschi et al. (2008) proposed that academic inventors on at least one patent application publish more and better-quality papers than non-patenting academics based on longitudinal data for 592 Italian academic inventors. They also suggested that the positive effects of patenting on publication vary according to scientific field, being especially strong in pharmaceutical and electronic sciences. Park et al. (2008) found out that patent activity has a positive effect on publication based on the 16 years' panel data of Korean academics' patent and publication.

Another group of empirical studies reports substitution effects of patents. Agrawal and Henderson (2002) examined the effects of patents by using data on the departments of mechanical and electrical engineering at the Massachusetts Institute of Technology (MIT), and they showed that patenting is a minority activity that does not represent the patterns of knowledge generation and transfer from MIT, and that patent volume does not have positive effects on publication. Calderini et al. (2009) empirically analyzed the complementary effects of academic patents in material engineering fields among Italian academics, and found strong substitution effects of academic patents in material chemistry. Based on their research results, they proposed that academic policies for intellectual property rights should be refined by field. Murray and Stern (2007) looked at patents related to 340 peer-reviewed scientific articles appearing between 1997 and 1999 in *Nature Biotechnology*, a leading publication in life sciences. They found a decline in article citation rate after a patent grant, and evidence for a modest anti-commons effect of patents for research produced in universities and other public institutions. Oh (2009) applied the regression model in the form of quadratic equations to clarify the mutual impact between publication and patenting in Korea. He showed that the effect of publication on patenting is positively significant, but the impact of patenting on publication is not positively significant, and so he suggested that journal publication and patenting are correlated in the long term trend but that there is no causal relationship between them.

Some other previous literature has proposed that the relationship of patents and publications can be expressed as an inverse U-shape rather than as a linear complementary or substitution relationship (Crespi et al. 2011; Fabrizio and Di Minin 2008). Crespi et al. (2011) examined the effects of increased patenting activities on other channels of knowledge transfer between universities and industry in the UK context. They found that academic patenting complements publishing at least up to a certain point of patent output, after which there is some evidence of substitution effects. They presented empirical evidence that patents have positive effects on other knowledge transfer channels such as joint research agreements with industry, contract research agreements, consultancy work, joint supervision of Ph.D. students, and equity interests in new companies (spin-offs), but also of an inverted U-shaped relationship between patents and other knowledge transfer channels.

As we have seen from this brief literature review, the relationship between patents and publications is controversial, and evidence for a complementary or substitution effect of patents varies according to the scientific field and the academic environment. On the other hand, the effects of patents on other knowledge transfer channels have not been fully explained, especially in the context of research collaboration with heterogeneous actors (Crespi et al. 2011). While university-industry collaboration becomes a key factor to facilitates knowledge transfer and creates possibility for new innovative research (Etzkowitz et al. 2000), many studies proposed the importance of university-industry collaboration and its effects on academic performance (Ho et al. 2016; Tijssen 2006; Wong and Singh 2013). Some previous studies reported the positive effects of research collaboration on academic publications (Ho et al. 2016), and some other previous studies analyzed that the university-industry co-publications have a significant positive influence on universities' technology commercialization outputs such as patenting, spin-off formation and technology licensing (Tijssen 2006; Wong and Singh 2013). However, few studies have analyzed the interrelationship between the academic patents and research collaboration, especially the effects of the academic patents on research collaboration with heterogeneous researcher actors such as industry and public research institutes (Crespi et al. 2011). Patents have the characteristics of monopoly and would rather increase the competitive relation between university and industry to get the ownership of patents (Dosi et al. 2010), while many policies use academic patents as a main instrument to enhance the university-industry linkages and innovation research (Grimaldi et al. 2011; Mowery et al. 2001). It is crucial to conduct the research on what are the academic patents' effects on research collaboration with heterogeneous actors as well as academic publication based on empirical data analysis. Moreover, most previous empirical studies have been conducted in a US or EU context, and very few in an Asian context (Ho et al. 2016; Oh 2009; Park et al. 2008; Wang and Guan 2010). Therefore, this study analyzes the effects of patents on publication and research collaboration between university, industry and public research institutes in the Korean academic context.

3 Method

3.1 Data

The study selected 46 of the 191 four-year universities in Korea based on a previous study (Shin 2009b) that classified the Korean universities by research performance. The 46 selected universities have relatively strong research performance. In the period of 2003–2005, they each turned out more than twenty doctoral graduates per year, and produced an average of one hundred articles or more. Using stratified sampling, 632 faculty members at the 46 universities were selected in disciplines in the natural sciences, bio sciences, and engineering sciences. The selected faculty members are representative of the faculty populations in the STEM fields at the 46 universities (23,390 full-time faculty members) in terms of gender, age, discipline and institution type, as shown in Table 1. The study collected panel data for the four years of 2008–2011 from multiple data sources. First, the 632 Korean faculty members' personal profiles, including gender, previous work experience, career and academic background, and research performance such as article publications and patents were drawn from the Korean researcher information (KRI) database of the National Research Foundation of Korea. KRI is the National Academic Performance Data Provision Service that provides the integrated research achievements and academic information of researchers from universities and research institutions in Korea. Second, bibliographic data on co-author information in their article publications was

Table 1 Population and sample comparison for the variables in the study. *Source*: 2009 Report on the Survey of Academic Research Activities, National Research Foundation of Korea (2010)

		Population	Sample
Gender	Male	30,791 (85.0%)	533 (84.3%)
	Female	5440 (15.0%)	99 (15.7%)
Age	Under 30	4049 (11.2%)	83 (13.1%)
	40–49	14,080 (38.9%)	297 (47.0%)
	50–59	13,856 (38.2%)	222 (35.1%)
	Over 60	4246 (11.7%)	30 (4.8%)
Discipline	Bio sciences	8785 (37.6%)	232 (36.7%)
	Engineering sciences	7590 (32.4%)	212 (33.5%)
	Natural sciences	7015 (30.0%)	188 (29.8%)
Institutional type	Public	11,674 (32.2%)	204 (32.3%)
	Private	24,557 (67.8%)	428 (67.7%)
Institutional location	Major cities	14,144 (39.0%)	311 (49.2%)
	Other	22,087 (61.0%)	321 (50.8%)
Total		23,390 (100.0%)	632 (100.0%)

The data for population and academic disciplines are based on 23,390 full time academics in STEM fields at 46 universities. The data for other items such as gender, age, institutional type, and location are based on 36,231 full time academics in STEM fields at 191 four-year universities checked from the Research Information Service System (RISS) for Korean Citation Index (KCI), the ISI Web of Science (WoS) for Science Citation Index (SCI) and the SCOPUS database as well as KRI. Patent information was collected from KRI, but the Korea Intellectual Property Rights Information Service (KIPRIS) was also used to check the detail information for academic patents. Third, information on the institutional characteristics of the 46 universities, such as type of institution, location, ratio of graduates, the number of faculty members, the size of the technology transfer office (TTO) and research funding, was sourced from the National Higher Education Data Provision Service (*Daehakalimi*).

3.2 Variables and analytical strategy

This study considers patenting activity to be an institutionalization of university–industry cooperation, because academic patenting is mainly used as an indicator to evaluate the university-industry linkages and research commercialization, and academics have paid more attention to patenting activities since the universities have been able to gain ownership of patents with the support of government funding (Agrawal and Henderson 2002; D'Este and Patel 2007; D'Este and Perkmann 2011; Narin et al. 1997; Owen-Smith and Powell 2001).

The dependent variables of this study were divided into three types: research publications, research collaboration with researchers in industries (UI research collaboration), and research collaboration with researchers in public research institutes (UG research collaboration). Research publications were measured as number of academic journal article publications (KCI, SCI, and SCOPUS articles). Coauthoring patterns were used as a proxy variable for research collaboration (Giunta et al. 2016; Leydesdorff and Sun 2009) because coauthorship data has merits about measurements, verifiability and stability (Katz and Martin 1997). Coauthoring patterns were measured by considering the affiliations of the coauthors of a publication (i.e., with a university, industry, or public research institute). In this study, research collaboration was measured by two types for descriptive analysis and regression analysis. At first, UI research collaboration was measured both as the percentage of all academic journal publications that list an author affiliation that refers to industry (a for-profit business company), and as the dummy variable whether there are academic journal publications having an author affiliation that refers to industry. UG research collaboration was measured both as the percentage of all academic journal publications that list an author affiliation that refers to a public research institute (a governmental organization) and as the dummy variable whether there are academic journal publications having an author affiliation that refers to a public research institute.

Academic patents were the main independent variables in this study. Academic patents were measured by the number of applications for domestic and international patents. To examine the effects of academic patents on publications and collaboration, the analysis controlled for characteristics of individual academics and features of their institutions. Academics' characteristics included gender, rank (professor or associate professor, assistant professor or lecturer), career in a university (years since full-time lecturer), country of Ph.D. training (Ph.D. obtained at a foreign university or at a domestic university), academic discipline (natural science, engineering science, bio-medical science), and previous work experience. Work experiences before seeking appointment to full-time lecturer in a university were divided into postdoctoral fellowships in universities, work in private industries, and work in public research institutes. Institutional features included institutional type (private university or public university), location (major cities or others), ratio of graduate students, number of full-time faculty members, the size of the TTO (the number of staff in industry-academic cooperation foundation in a university), and research funding (government funds, private funds, internal funds). The definitions and measures of these variables are summarized in Table 2.

To examine the effects of academic patents on research collaboration, academic research publications were also included as a control variable, because academic visibility and prestige, which lead to research collaboration, depend on cumulative previous research performance, as described by the Matthew effect (Abramo et al. 2009; Crespi et al. 2011; Merton 1973).

The study applied a fixed effect negative binominal regression model and a random effect negative binominal regression model to analyze the effects of academic patenting on publication. Also the study applied a fixed effect logit model and a random effect logit model to examine the effects of academic patenting on collaboration. A fixed effect model has an advantage for estimating unbiased coefficients because it assumes that unique attributes of individuals such as research preference, motivation, IQ, and effort are constant over time, and the potential bias brought about by unobservable heterogeneity can be eliminated by using panel data (Greene 2003). Along with the fixed effect model, this study controls for remaining unobserved heterogeneity by estimating a random effect model.

To analyze the effects of patenting on academic research publication, time lags between patenting activities and publications were considered because research should not be published before applying for patents. This study, therefore, applied two different models: the first model does not take account of a time lag between academic patent activities and publications, and the second model accounts for a one-year time lag, based on the previous literature (Dornbusch et al. 2013; Wang and Guan 2010). The analysis models are represented as follows:

$$\begin{gathered}\mathrm{Pub_{it}} = \alpha + \beta_0 P_{it} + \beta_1 P_{it}^2 + \beta_2 x_{it} + \beta_3 U_{jt} + \mu_i + e_{it} \\ (\mathrm{i} = 1, 2, \ldots, \mathrm{n}, \mathrm{j} = 1, 2, \ldots, \mathrm{m} \text{ and } \mathrm{t} = 1, 2, \ldots, \mathrm{T})\end{gathered} \tag{1}$$

$$\begin{gathered}\mathrm{Pub_{it}} = \alpha + \beta_0 P_{it-1} + \beta_1 P_{it-1}^2 + \beta_2 x_{it} + \beta_3 U_{jt} + \mu_i + e_{it} \\ (\mathrm{i} = 1, 2, \ldots, \mathrm{n}, \mathrm{j} = 1, 2, \ldots, \mathrm{m} \text{ and } \mathrm{t} = 1, 2, \ldots, \mathrm{T})\end{gathered} \tag{2}$$

where $\mathrm{Pub_{it}}$ is total article publications, $\mathrm{P_{it}}$ or P_{it-1} is academic patents, x_{it} is a set of individual academic's characteristics, U_{jt} is a set of institutional features, and μ_i is an individual fixed effect; and

$$\begin{gathered}\mathrm{Y_{it}} = \alpha + \beta_0 P_{it} + \beta_1 P_{it}^2 + \beta_2 Pub_{it} + \beta_3 x_{it} + \beta_4 U_{jt} + \mu_i + e_{it} \\ (\mathrm{i} = 1, 2, \ldots, \mathrm{n}, \mathrm{j} = 1, 2, \ldots, \mathrm{m} \text{ and } \mathrm{t} = 1, 2, \ldots, \mathrm{T})\end{gathered} \tag{3}$$

$$\begin{gathered}\mathrm{Y_{it}} = \alpha + \beta_0 P_{it-1} + \beta_1 P_{it-1}^2 + \beta_2 Pub_{it} + \beta_3 x_{it} + \beta_4 U_{jt} + \mu_i + e_{it} \\ (\mathrm{i} = 1, 2, \ldots, \mathrm{n}, \mathrm{j} = 1, 2, \ldots, \mathrm{m} \text{ and } \mathrm{t} = 1, 2, \ldots, \mathrm{T})\end{gathered} \tag{4}$$

where $\mathrm{Y_{it}}$ is dependent variables (i.e., UI research collaboration, UG research collaboration), $\mathrm{P_{it}}$ or $\mathrm{P_{it-1}}$ is academic patents, $\mathrm{Pub_{it}}$ is total article publications, x_{it} is a set of individual academic's characteristics, U_{jt} is a set of institutional features, and μ_i is an individual fixed effect.

Table 2 Variables

Variables	Measurement	
Independent variables		
Academic patent	Number of applications for $patents_{it}$	Number of applications for domestic and international patents by academic i in year t
	Number of applications for $patents_{it-1}$	Number of applications for domestic and international patents by academic i in year t – 1
Demographic background	$Gender_{i}$	Male = 1, Female = 0
	$Rank_{it}$	Professor/Associate professor = 1, Assistant professor/Lecturer = 0 by academic i in year t
	$Career_{it}$	Years since full-time lecturer by academic i in year t
Academic background	Country of PhD $training_{i}$	Overseas university = 1, Korean university = 0
	$Discipline_{i}$	Bio sciences, Engineering sciences, Natural sciences (criterion variable)
Previous work experience	Postdoctoral $fellowship_{i}$	Yes = 1 or No = 0
	Private $industry_{i}$	Yes = 1 or No = 0
	Public research $institute_{i}$	Yes = 1 or No = 0
Physical characteristics of universities	Type of $university_{j}$	Private = 1, Public = 0
	Location of $university_{j}$	Major cities = 1, others = 0
	Ratio of graduate $students_{jt}$	No. of graduate students/No. of undergraduate students in university j in year t
	No. of $faculty_{jt}$	Number of full-time faculty members in university j in year t
	TTO $size_{jt}$	Number of staff in Industry-Academic Cooperation Foundation in university j in year t
Research funding	Government $funds_{jt}$	Government research funds in university j in year t (log)
	Private $funds_{jt}$	Research funds from private sector in university j in year t (log)
	Internal $funds_{jt}$	On-campus funds in university j in year t (log)
Dependent variables		
Research publication	Total article $publications_{it}$	Number of KCI, SCI/SCOPUS indexed articles by academic i in year t
Research collaboration	UI research $collaboration_{it}$	Percentage (%) of co-authored articles with private sector by academic i in year t There are co-authored articles with private sector by academic i in year t = 1 or No = 0
	UG research $collaboration_{it}$	Percentage (%) of co-authored articles with public research institutes by academic i in year t There are co-authored articles with public research institutes by academic i in year t = 1 or No = 0

4 Results

4.1 Descriptive statistics

Table 3 presents the descriptive statistics of the sample in this study. The sample consists of 533 male and 99 female academics, with academic careers of 14.2 years on average since they became full-time university lecturers. Their distribution by discipline is 29.75% in natural sciences, 33.54% in engineering sciences, and 36.71% in bio-medical sciences. Regarding their previous work experience, 277 (43.83%) had received postdoctoral fellowships, 138 (21.84%) had working experience in private industries, and 205 (32.44%) had working experience in public research institutes.

Table 3 Descriptive statistics

Individual characteristics		
Variables	No.	%
Demographic background		
Gender		
Male	533	84.34
Female	99	15.66
Rank		
Professor or associate professor	526	83.23
Assistant professor or lecturer	106	16.77
Previous work experience		
Postdoctoral fellowship		
Yes	277	43.83
No	355	56.17
Private industry		
Yes	138	21.84
No	494	78.16
Public research institute		
Yes	205	32.44
No	427	67.56
Academic background		
Discipline		
Natural sciences	188	29.75
Engineering sciences	212	33.54
Bio sciences	232	36.71
Country of Ph.D. training		
Overseas university	302	47.78
Korean university	330	52.22

Variables	N	Mean	SD	Max	Min
Total article publications (annual)	632	4.25	4.72	50	0
UI research collaboration (annual, %)	632	5.91	16.39	100	0
UG research collaboration (annual, %)	632	17.34	27.79	100	0
Patents (annual)	632	0.76	2.21	32	0
Academic career (annual, year)	632	14.22	8.11	35.5	2.5

Table 3 (continued)

University characteristics

Variables	Number of universities		Number of faculty members	
	No.	%	No.	%
Type				
Public	14	30.43	204	32.38
Private	32	69.57	428	67.72
Location				
Major cities	21	45.65	311	49.21
Other	25	54.35	321	50.79

Variables	Mean	SD	Max	Min
Ratio of graduate students (annual)	0.49	0.36	1.90	0.09
No. of faculty (annual)	841.64	433.69	1997.5	204.25
TTO size (annual)	40.13	18.58	71.75	6.5
Government funding (annual, $)	78,700,000	93,600,000	410,000,000	7,582,706
Private funding (annual, $)	11,200,000	12,800,000	43,900,000	433,885.5
Internal funding (annual, $)	5,138,733	4,140,028	17,300,000	263,945

Table 4 Correlations between main research variables

	Patent_{t-1}	Publication_t	UI collaboration_t	UG collaboration_t
Patent_{t-1}	1.000			
Publication_t	0.215***	1.000		
UI collaboration_t	0.100***	0.069***	1.000	
UG collaboration_t	−0.001	0.227***	0.028	1.000

In this sample, 204 of the academics are affiliated with 14 public universities, and 428 academics are affiliated with 32 private universities. The 46 Korean universities represented have an average of 842 faculty members and 40 staff members in their TTOs. The ratio of graduate students, a proxy variable for a research university, is 49% on average.

The academics in this study published an average of 4.25 journal articles per year, while they applied for an average of 0.76 patents per year. Regarding research collaboration, the rate of coauthored publications with researchers in private industries (UI research collaboration) is 5.91% per year on average, and the rate of coauthored publications with researchers in public research institutes (UG research collaboration) is 17.34% per year on average.

Table 4 shows the correlations between each of the main research variables: patents, publications, UI research collaboration, and UG research collaboration. These variables are weakly correlated. For example, the Pearson correlation coefficient between patents and publications is 0.215 and between patents and UI research collaboration is 0.100, while UG research collaboration is not significantly correlated with patents.

4.2 Regression analysis

Tables 5, 6, and 7 present the results of the regression analysis according to the dependent variables. The results of the fixed effect negative binomial regression and the random effect negative binomial regression for academic publication activity are shown in Table 5. This study employed the Hausman test to differentiate between the fixed effect model and the random effect model. As a result, the fixed effect model is preferred ($\chi^2(10) = 47.93^{***}$ in models 1 and 3, $\chi^2(10) = 53.17^{***}$ in models 2 and 4). Academic patenting has positive effects on publication in model 1, but model 2, which considers time lags between patents (t − 1) and publications (t), suggests that publications have a non-linear inverted U-shaped relationship with academic patents. This means that academic patenting may complement publishing up to a certain point of patenting activity, but after that point, patenting may have substitution effects on publishing. The random effect negative binomial regression (models 3 and 4) has similar results as shown in Table 5.

The results suggest that disciplinary fields and academic working experience have positive effects on publication. For example, academics in the bio-medical sciences produce more journal articles than those in the natural sciences. Previous working experience in postdoctoral fellowships or public research institutes is positively associated with academic publishing. In terms of academic rank and career, professors or associate professors publish more journal articles than assistant professors or lecturers when controlling for academic career, while relatively young academics whose academic careers have been short tend to produce more journal article publications than older academics whose careers have been longer when controlling for academic rank. In addition, academics at universities located in major cities produce more journal articles than those at local universities.

Tables 6 and 7 show the panel logit results for research collaboration. The fixed effect model is preferred in the case of UI research collaboration, based on the Hausman test ($\chi^2(11) = 23.48^{*}$ in models 5 and 7), while the random effect model is preferred in the other cases. Academic patenting is shown to have a positive effect on university–industry research collaboration in model 8, applying the random effect model, as shown in Table 6, but academic patenting activity does not have a statistically significant effect on research collaboration with researchers in public research institutes, as shown in Table 7. Academic article publication activity is positively related to research collaboration with researchers in industry and public research institutes.

In terms of effects on university–industry research collaboration, academics in bio science and engineering fields or who have work experience in industries are more active in research collaboration with researchers in private industries, as shown in the random effect model 8. On the other hand, academics in bio science or who have work experience in postdoctoral fellowships or public research institutes are more active in research collaboration with research collaboration with researchers in public research institutes. Private funding is negatively associated with research collaboration with researchers in public research institutes.

5 Discussion and conclusion

This study aimed to investigate whether active academic patenting enhances or reduces research collaboration with various researchers from industry and public research institutes as well as academic publication in Korean academic case. The results of this

Table 5 Negative binomial regression on total article publication

	Fixed effect model				Random effect model			
	Model 1 (T)		Model 2 (T – 1)		Model 3 (T)		Model 4 (T – 1)	
	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err
$Patent_{it}$ ($Patent_{it-1}$)	0.026*	0.012	0.034**	0.011	0.050***	0.011	0.056***	0.011
$Patent^2_{it}$ ($Patent^2_{it-1}$)	−0.001	0.000	−0.001**	0.000	−0.001*	0.000	−0.002***	0.000
$Gender_i$					0.190	0.100	0.207*	0.1
$Rank_{it}$	0.188**	0.066	0.173**	0.066	0.185**	0.059	0.163**	0.058
$Career_{it}$	−0.022	0.012	−0.022	0.012	−0.022***	0.005	−0.022***	0.005
Overseas Ph.D. $_i$					−0.066	0.074	−0.063	0.074
$Bioscience_i$					0.395***	0.091	0.393***	0.091
$Engineering_i$					0.183	0.098	0.182	0.099
Postdoc. $_i$					0.163*	0.076	0.157*	0.076
Private $industry_i$					−0.119	0.096	−0.121	0.096
Public research $institute_i$					0.188*	0.078	0.174*	0.079
Type of univ. $_j$					−0.120	0.098	−0.128	0.098
Location of univ. $_j$					0.162	0.087	0.174*	0.087
No. of $faculty_{jt}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TTO $size_{jt}$	−0.001	0.001	−0.001	0.001	0.000	0.001	0.000	0.001
Ratio of graduate $students_{jt}$	−0.268	0.177	−0.298	0.177	0.090	0.110	0.056	0.11
Government $funds_{jt}$	0.027	0.081	0.024	0.081	0.071	0.066	0.076	0.066
Private $funds_{jt}$	0.036	0.048	0.035	0.047	0.034	0.039	0.032	0.039
Internal $funds_{jt}$	0.032	0.03	0.039	0.03	0.012	0.026	0.022	0.026
Constant	1.337	1.209	1.356	1.214	0.251	0.938	0.116	0.94
N of groups (N of obs.)	591 (2364)		591 (2364)		632 (2528)		632 (2528)	
Log likelihood	−3251.330		−3248.944		−5637.830		−5635.796	
Wald Chi2	21.04*		24.14**		144.75***		147.08***	

*$p<0.05$, **$p<0.01$, ***$p<0.001$

Table 6 Regression on UI research collaboration

	Fixed effect model				Random effect model			
	Model 5 (T)		Model 6 (T – 1)		Model 7 (T)		Model 8 (T – 1)	
	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err
$Patent_{it}$ ($Patent_{it-1}$)	– 0.029	0.076	0.040	0.067	0.107*	0.055	0.149**	0.051
$Patent^2_{it}$ ($Patent^2_{it-1}$)	– 0.004	0.005	0.001	0.002	– 0.005	0.002	– 0.003	0.002
$Publication_{it}$	0.180***	0.028	0.178***	0.028	0.189***	0.018	0.183***	0.018
$Gender_i$					– 0.072	0.267	– 0.083	0.265
$Rank_{it}$	– 0.135	0.384	– 0.139	0.384	– 0.337	0.245	– 0.376	0.244
$Career_{it}$	– 0.269*	0.118	– 0.262*	0.118	– 0.009	0.014	– 0.010	0.013
Overseas Ph.D. $_i$					0.274	0.195	0.290	0.193
$Bioscience_i$					0.850*	0.266	0.837**	0.264
$Engineering_i$					1.288***	0.277	1.234***	0.274
Postdoc. $_i$					– 0.246	0.202	– 0.273	0.201
Private $industry_i$					0.823***	0.232	0.762***	0.231
Public research $institute_i$					– 0.039	0.207	– 0.037	0.206
Type of univ. $_j$					0.259	0.281	0.193	0.279
Location of univ. $_j$					– 0.139	0.239	– 0.126	0.238
No. of $faculty_{jt}$	0.004*	0.002	0.004*	0.002	0.000	0.000	0.000	0.000
TTO $size_{jt}$	0.014	0.009	0.013	0.009	0.006	0.006	0.005	0.006
Ratio of graduate $students_{jt}$	– 0.568	0.955	– 0.664	0.957	0.480	0.387	0.328	0.389
Government $funds_{jt}$	0.164	0.531	0.153	0.532	0.157	0.260	0.180	0.259
Private $funds_{jt}$	– 0.001	0.285	0.032	0.282	– 0.088	0.154	– 0.099	0.153
Internal $funds_{jt}$	0.308	0.186	0.302	0.186	0.041	0.109	0.060	0.109
Constant	–	–	–	–	– 6.427	3.661	– 6.708	3.652
N of groups (N of obs.)	235 (940)		235 (940)		632 (2528)		632 (2528)	
LR chi2 (Wald chi2)	60.60***		57.62***		180.94***		185.42***	
Log likelihood	– 325.077		– 326.569		– 967.359		– 963.597	

$*p < 0.05$, $**p < 0.01$, $***p < 0.001$

research suggest that the relation between academic patents and publications has a non-linear inverted U-shape, in that academic patenting is positively associated with publishing up to a certain point, after which it is negatively related to publishing. In terms of the effects on research collaboration, the main independent variables in this study, academic patenting has positive effects on research collaboration with industry, but academic patenting activity does not have statistically significant effects on research collaboration with researchers in public research institutes. These findings support the results of previous studies that show an inverse U-shaped relation between publications

Table 7 Regression on UG research collaboration

	Fixed effect model				Random effect model			
	Model 9 (T)		Model 10 (T – 1)		Model 11 (T)		Model 12 (T – 1)	
	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err
$Patent_{it}$ ($Patent_{it-1}$)	– 0.006	0.085	– 0.008	0.075	– 0.011	0.063	– 0.006	0.059
$Patent^2_{it}$ ($Patent^2_{it-1}$)	– 0.004	0.005	0.000	0.003	– 0.003	0.003	0.000	0.002
$Publication_{it}$	0.498***	0.039	0.406***	0.038	0.425***	0.028	0.420***	0.027
$Gender_i$					0.514	0.278	0.475	0.276
$Rank_{it}$	0.089	0.380	0.089	0.379	– 0.402	0.247	– 0.399	0.246
$Career_{it}$	– 0.164	0.103	– 0.165	0.103	– 0.009	0.013	– 0.010	0.013
Overseas Ph.D. $_i$					0.171	0.201	0.185	0.200
$Bioscience_i$					1.072***	0.252	1.046***	0.250
$Engineering_i$					0.267	0.271	0.231	0.269
Postdoc. $_i$					0.470*	0.207	0.466*	0.205
Private $industry_i$					– 0.265	0.260	– 0.293	0.259
Public research $institute_i$					0.705***	0.212	0.700***	0.211
Type of univ. $_j$					– 0.371	0.280	– 0.406	0.279
Location of univ. $_j$					– 0.005	0.242	0.016	0.241
No. of $faculty_{jt}$	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.000
TTO $size_{jt}$	0.009	0.009	0.009	0.009	0.006	0.006	0.005	0.006
Ratio of graduate $students_{jt}$	1.432	1.053	1.498	1.049	– 0.034	0.403	– 0.053	0.403
Government $funds_{jt}$	1.026*	0.472	1.024*	0.472	0.429	0.252	0.403	0.251
Private $funds_{jt}$	– 0.103	0.264	– 0.095	0.264	– 0.380*	0.151	– 0.374*	0.150
Internal $funds_{jt}$	0.195	0.205	0.201	0.206	0.134	0.109	0.133	0.109
Constant	–	–	–	–	– 6.940	3.573	– 6.471	3.551
N of groups (N of obs.)	295 (1180)		296 (1184)		632 (2528)		632 (2528)	
LR chi2 (Wald chi2)	178.63***		176.83***		300.74***		299.91***	
Log likelihood	– 361.407		– 363.690		– 1158.179		– 1162.012	

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

and patents (Crespi et al. 2011; Fabrizio and Di Minin 2008), and expand the study on the effects of patents on research collaboration between heterogeneous researchers.

This study shows that a strong emphasis on commercialization is a limited approach to transferring academic knowledge to society. Korean university research has developed quickly since the mid-1990s, and emphasized research outputs and academic commercialization rather than academic knowledge's public goods and knowledge transfer itself. Policy makers and scientists play a main role in using patents as a proxy variable for innovation, which can create a bubble effect of academic patents. The Korean Intellectual Property Office (2013) reported that the number of annual technology developments in Korea was 12,842, similar to that in the other advanced countries such as the United States and in the European Union, but the rate of technology transfer by universities was 19.5%, which is relatively very low compared with 38.0% in the United States. Academic patenting activities have been strongly emphasized as incentives for technology transfer, but academics still seek to accumulate high numbers of patents to gain good evaluations of research performance rather than to activate technology transfer (Yun et al. 2007). Government policies and university administrators pursue active university–industry cooperation and knowledge transfer through academic patent activities, but academic patents have ambivalent attributes in that patents are used as a reward for technology transfer, but cause monopolization and hinder the sharing of knowledge and technology with other researchers (Dosi et al. 2010). The expansion of intellectual property rights such as patents results in the privatization of scientific knowledge, which inhibits the free flow of academic knowledge (Murray and Stern 2007). Moreover, this trend leads to the incurring of transaction costs, publication delays, and increasing direct influence of industry and government on research agendas (Geuna and Nesta 2006; Grimm and Jaenicke 2015).

In contrast to academic patenting activity, academic article publication activity is positively related to research collaboration with researchers in industry or public research institutes. Academic fields and academics' individual work experience in industry or public research institutes are also positively associated with research collaboration. Scientific researchers have recently gained more active job mobility in Korea, as more academics now have a greater variety of previous professional experiences such as postdoctoral fellowships and work experience in companies or public research institutes before going into faculty job positions at universities, and researchers move from universities to companies and public research institutes as well. Such job mobility naturally acts to support the development of collaborative activities and the transfer of knowledge and technology (Dietz and Bozeman 2005). The results of this study show that academics having work experience in industry are more actively engaged in research collaboration with industrial researchers, while academics having work experience in public research institutes are more active in research collaboration with researchers in public research institutes. These findings recall Bekkers and Freitas's (2008) description of how different academic fields have different channels for knowledge or technology transfer. The results of this study also present distinct attributes of disciplinary fields. For example, academics in engineering or bio science have more research collaboration with industries, while academics in bioscience tend to collaborate more with researchers in public research institutes than those in natural science. The findings suggest that academics' patenting activities still have limited effects on research publishing and research collaboration with researchers in public research institutes, and that these effects are related to specific academic disciplinary areas.

Despite the significant findings, this study has limitations. First, the study did not consider the effect of technological and scientific parks because of data limitation. As technological and scientific parks are foundation to promote university-industry linkages, it is important to explore its effects on university-industry research cooperation in future research. Second, Technology Transfer Offices (TTO) also play a key role to enhance external and internal activities of university-industry-public research institutes cooperation, and therefore it is a crucial to examine the role of TTO for the further research. Third, this study also did not examine the causal relations between academic patenting, publication and research collaboration activities. For the further research, it is necessary to conduct a longitudinal analysis of academics' patenting activity and its effects on their publication and research collaboration. Finally, the interrelations and various patterns of research collaboration between heterogeneous researchers in academia, industry and public research institutes should be explored using an in-depth qualitative approach.

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