Modes of Knowledge Transfer from PROs and Firm Performance: The Case of Korea

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This paper aims to conceptualize the modes of knowledge transfer from PROs and to identify the impacts of the modes on firm performance. To these ends, this utilizes the Survey on Korean industry-university/PRI relationships to estimate the impacts of its mode in terms of the innovation probability, patents and sales of Korean firms. First, we find that non-IP modes of knowledge transfer and patent/licensing from PROs facilitate the innovation probability or the patent-filing of firms, while business activity does not. Second, non-IP modes of knowledge transfer and patent/licensing from PROs contribute to industrial innovation, by creating new knowledge through patents, but they face limitations in industrializing knowledge through sales. Third, non-IP modes of knowledge transfer facilitate industrial innovation, through the patent-filing, only in the high-tech industries, while they still face limitations, through sales, even in these industries. This reflect the nature of knowledge industrialization in Korea, and we suggest several policy implications.

Keywords: Knowledge transfer, University-industry interactions

JEL Classification: O30, O32, O43

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I. Introduction

With the fast-paced global competition in this technological age, a firm's links to universities as a source of new knowledge have become more important now than in the past (Bettis and Hitt 1995; Etzkowitz and Leydesdorff 1997). This is particularly the case for the industrialization as well as for the creation of knowledge. Thus, in addition to the traditional mission of the university, its "third mission" in economic development is currently emphasized (Etzkowitz and Leydesdorff 2000).

Policymakers have focused much attention to knowledge transfer from universities to firms in recognition of the fact that public research should be utilized enough to generate social and economic benefits (Mowery and Sampat 2005). In this vein, developed countries have searched for ways to facilitate the transfer of technology in the public domain. An example is the *Bayh-Dole Act* of 1980 in the U.S., which allowed universities the ownership of inventions generated by public funds. Since then, OECD countries have emulated the *Act* to adopt policies for intellectual property (*IP*) management (OECD 2003). In Korea, the *Laws on Industrial Education and Industry-University Cooperation* was enacted in 2003.

In the academe, the Triple-Helix thesis emphasizes both the economic and social roles of universities (Etzkowitz and Leydesdorff 1997). Based on the Triple-Helix model of industry-university-government relations, this thesis argues that universities need to be directly linked to industries to maximize the industrialization of knowledge. On the other hand, the New Economics of Science presents the opposite view. It emphasizes the innate function of universities, arguing that the too close relationship between the two is detrimental to the scientific potentials of a nation and that a proper division of labor is needed (Dasgupta and David 1994).

The industry-university relationships differ according to country and should be understood in the context of each country (Eun *et al.* 2006). The concept of entrepreneurial universities, the most developed form of knowledge transfer, is observed in *Stanford University in Silicon Valley* and *Peking University* and *Tsinghua University* in China. On the other hand, Japanese universities, having focused on education and research, are in transition to being entrepreneurial. These relationships or modes of knowledge transfer vary in response to the needs of the time: the innate roles of the university, education, and research still remain, but their relative importance as a mode of knowledge transfer is changing. This study starts from this point.

In Korea, like in Japan, the government's policy is moving towards facilitating patent/licensing, spin-offs, and so on, and universities are in transition to being entrepreneurial universities. In other words, formal and IP modes of knowledge transfer are emphasized now more than before. In this situation, the role of Korean universities could be underestimated if an evaluation would be made on the aspect of knowledge industrialization. Therefore, this paper intends to examine all possible modes of knowledge transfer from universities to estimate their impact on various innovation outcomes. Considering the key role of PRIs in national R&D since the 1970's, this includes them into the analysis. Specifically, this paper tries to answer the following questions: 1) How do the modes of knowledge transfer from PROs affect the performance of Korean firms? 2) Is there any difference in the impact of each mode according to sector?

To this end, this paper conducts an empirical analysis based on a *Survey on Korean Industry-University/PRI Relationships*, which was conducted jointly by the STEPI and the EAI (Center for Economic Catch-up) with the support of the IDRC. To allow for data credibility, the *Survey* is merged with the financial statements of the *KIS VALUE* data compiled by a credit rating agency. This study tries to conceptualize the modes of knowledge transfer from PROs by covering all possible information channels and interactions with universities and PRI, and to estimate the impact of each mode on the innovation probability, patents, and sales of firms.

This paper is structured as follows. Section II reviews the evolution of industry-PRO relationships in Korea. Section III conceptualizes the modes of knowledge transfer from PROs, based on which the Korean case is analyzed. Section IV presents the hypotheses and model specifications and conducts the empirical analysis on the impact of each mode of knowledge transfer on firm performance. Finally, Section V provides the summary and conclusions.

II. Evolution of Industry-PRO Relationships in Korea

The industry-PRO relationships in Korea have evolved with the influence of the government's science and technology (*S&T*) policy. In the

1960s, with Korea having been left with no industrial infrastructure, the government began economic development by establishing legal and organizational frameworks. The Korea Institute of Science and Technology (*KIST*) and the Ministry of Science and Technology (*MOST*) were established in 1966 and 1967, respectively, and the *Science and Technology Promotion Law* was enacted in 1967. In this period, mechanical and skilled labor education was given importance.

In the 1970s, as Korea was in transition from light to heavy industries, the government tried to promote national R&D by establishing PRIs because the R&D capacities of universities and firms were weak. A number of PRIs were established based on the *Special Research Institute Promotion Law* of 1973 in the fields of machinery, shipbuilding, chemical engineering, marine science, and electronics. According to the MOST (2006), the percentage of PRI in total R&D expenditure exceeded those of universities and firms, although it has steadily increased in the latter. Meanwhile, *chaebol* firms based on heavy industries began to grow rapidly from the mid-1970s. The Korean government played a crucial role in their growth by selecting and providing them with exclusive advantages, quality manpower, and resources. Engineering and science education was given importance in this period.

In the 1980s, faced with regulations on technology transfers by advanced countries, the Korean government placed priority on building the national R&D capacity (Kim 1993). Most of all, the government initiated the National R&D programs in 1982 with emphasis on large-scale national projects. Several ministries were involved in the programs with a large amount of R&D budget and investment. Since then, the industry-university or PRI cooperation in Korea has being pursuing specific programs. An example is the DRAM semiconductor, which was co-developed by private firms and the *Electronics and Telecommunications Research Institute* (*ETRI*) to catch up with advanced countries(Lee and Lim 2001). The R&D capacities of universities, and, noticeably, industries grew beginning from the mid-1980s. Big firms and *chaebols* started in-house R&D by hiring quality scientists and engineers from abroad or by acquiring technology in collaboration with foreign partners, while universities shifted towards being research-based, thus conducting joint R&D with firms. As a result, the role of PRIs became smaller than it used to be from the 1970s to the 1980s (Song 2004). According to the MOST (2006), the percentage of total R&D expenditure of firms surpassed that of PRI. In this period, Korea, as a catch-up country, emphasized the imitation of technology as being more important than its creation. Thus, *chaebol* firms that led technological innovations benefited from their large-scale investment in R&D and the government's selective support (Lim 2006). As Kim (1993) mentioned, the dynamic growth of the Korean economy was possible then through the aggressive accumulation of technological capabilities by *chaebol* firms.[1]

In the 1990s, the R&D capacity of universities as well as industries grew noticeably. Since then, the ranking of Korea has been rising in terms of the number of SCI papers to which universities have contributed: Korea ranked 19th in 1996, with universities accounting for 83.0% of the contributions (Lee 1998). In this period, various policy measures were taken to support universities' research or to facilitate industry-university cooperation, such as the establishment of Science Research Centers (*SRCs*), Regional Research Centers (*RRCs*), and the *Brain Korea 21* (*BK21*) program. In the 2000s, the Korean government extended these measures into the second phase of the BK21 project: the *New University Regional Innovation* (*NURI*) project, the *Connect Korea* (*CK*), and the *Hub University for Industrial Collaboration* (*HUIC*) project (KRF 2006, 2007). Most importantly, laws and institutions related to knowledge industrialization were established in this period. The *Technology Transfer Promotion Law* was enacted in 2001, which prescribes that public universities should establish units or institutions in charge of technology transfer and training of specialists. The promotion of the industry-university cooperation gained more momentum as universities started to establish the so-called "industry-university cooperation foundation" in 2004, which was based on the enactment of the *Law on Industrial Education and Industry-University* Cooperation in 2003. As of 2007, 134 universities have established industry-university cooperation foundations within their campuses, out of which 59.8% (80 universities) has had TLOs. The number of TLOs increased rapidly especially in 2004, with 43 being newly established, compared with only 32 until 2003 (KRF 2007). Moreover, the industrialization of technology from PROs has grown fast recently (MOCIE 2007): the number of technology developed by PROs was recorded at 42,038 in 2006, with an increase of 22.1% from 34,439 in 2004. The number of technology transferred also increased by 65.4%, from 6,570 to 9,014, and the rate of technology transfer rose up to 21.4% from 18.5% during this period. The

[1] According to Ungson *et al.* (1997), as of 1996, business groups, *e.g., Samsung, Hyundai, LG*, and *Daewoo*, had about 80 affiliates and the top 30 largest chaebols were responsible for 40% of Korea's total output.

royalties from technology transfer were recorded at 82,030 million won in 2006, a 45.2% increase from 56,490 million won in 2004.[2] In terms of the type of technology, patent was used the most at 55.2% of the total technology; followed by know-how at 34.0%, others at 7.5%, trademark at 2.4%, and utility at 0.9%. By the type of transfer, PROs used license the most at 68.4%, followed by sale at 21.1% and others at 10.5%.

III. Modes of Knowledge Transfer from PROs

A. Conceptual Framework

Knowledge and technology are used often without being distinguished, maybe because each shares some characteristics with the other. However, knowledge is different from technology in terms of "purpose, degree of codification, type of storage, and degree of observability" (Landry *et al.* 2007). Knowledge is tacitly stored in people's head, intangible with the imprecise impact of its use and concretized theories and principle, while technology is codified in software or blueprint, tangible with the precise impact of its use and changing technological environments. Thus, knowledge is a broader concept than technology, and technology transfer is a much more limited set of activities than knowledge transfer.

There are a number of studies on the channels of technology transfer. Megantz (1996) argues that licensing is the most efficient channel, referring to M&A, new/joint venture, strategic alliance, and technology assignment as its alternatives. Sandelin (1994) mentions patent and licensing as the performance indicators of universities' technology transfer. A large part of the knowledge from universities is transferred to industries informally or in non-IP modes, although previous studies have focused mainly on citations (Spencer 2001), patents (Hall and Ziedonis 2001), and spin-offs (Link and Scott 2005). However, there are only a few studies that have tried to include informal modes of transfer. Landry *et al.* (2007) consider seven types of knowledge transfer activities — research submission, presentation, workshop, consulting, product

[2] Compared with advanced countries, however, the technology transfer activities of Korean PROs are less active. As of 2006, the rate of technology transfer is 24.2%, smaller than that of the U.S. (35.9%) and Europe (46.8%). In case of R&D productivity, the ratio is 1.5%, also smaller than that of the U.S. (4.8%) and Europe (3.5%) (Table A1).

development, business activity, and knowledge commercialization — to estimate the determinants of each type. Arvanitis *et al.* (2008) classify 19 forms of knowledge transfer into five categories — education, research, university technology utility, consulting, and informal contact of general information — to measure the impact of each form.

However, the above studies still have limitations: they either cover only a few modes or define no classified mode. Therefore, this paper tries to cover all possible interactions between firms and PROs to classify the modes of knowledge transfer — both IP and non-IP modes. This analysis is based on Eun *et al.*'s study (2006) that explains industry-university relationships in terms of the governance forms of knowledge industrialization through which knowledge flows from university to industry. They suggest two criteria for classifying a specific governance form: "economic efficiency" and "social contract." The former is the choice between market and hierarchy (X-axis), and the latter is related to how entrepreneurial universities are — teaching, research, or entrepreneurial (Y-axis) (see Figure A1). Ten types of knowledge industrialization forms are placed in a two-dimensional space: education in the bottom-middle part, being teaching oriented and neutral between market-like and hierarchical; joint conference in the bottom-left, being research oriented and market-like; joint research and joint research center in the middle-left, being research oriented and slightly market-like; technology sale and patent/license in the upper-left, being entrepreneurial and market-like; and spin-off, incubator, science park, and URE in the upper-right, being entrepreneurial and hierarchical.

B. Data

The *Survey on Korean Industry-University/PRI Relationships* follows the framework of the *Carnegie Mellon Survey* and the *Yale Survey*, with some modifications that reflect the Korean situation. This surveyed 500 manufacturing firms, covering the period of 2004-2006. The Survey includes a variety of information about industry-PRO interactions from the firms' perspectives: information channels and interactions, motives and obstacles, and so on. After being matched with the financial statements of *KIS VALUE*, for example, number of employee, R&D expenditure, and industry classification, a total of 383 samples finally qualified for the empirical analysis.

C. Modes of Knowledge Transfer from PROs in Korea

In the *Survey*, Korean firms were asked to evaluate the importance of 15 different information channels and interactions with PROs on a 4-point Likert scale. We grouped them into five modes of knowledge transfer: *Type 1* (Informal activity: space publication/reports, conferences/seminars, information exchange, and consulting), *Type 2* (Education: recently hired graduates and irregular personal exchange), *Type 3* (R&D cooperation: contract R&D, joint R&D, and R&D consortium), *Type 4* (Patent/licensing: patents and licenses), and *Type 5* (Business activity: technology incubators, technology parks, spin-offs, and university/PRI-run enterprises). Each mode is composed of firms that reported 2-4 on a 4-point Likert scale (above "important") in at least one of relevant channels and interactions. The first three are the non-IP modes, and the remaining two are the IP modes of transfer.

According to Table 1, Korean firms tend to use the non-IP modes more than the IP-modes of knowledge transfer. From universities, 62.6, 46.5, and 52.0% use informal activity, education, and R&D cooperation, respectively; while 35.2 and 21.4% conduct patent/licensing and business activity. From PRIs, 56.8, 36.2, and 39.7% use informal activity, education, and R&D cooperation, respectively, while 33.7 and 11.8% conduct patent/licensing and business activity. Consulting, recently hired graduate/personal exchange, and joint/contract R&D record a relatively higher score in the frequency and degree of importance, reflecting the importance placed on the innate function of universities or PRIs in Korea. Patent and licensing record a relatively high score, which implies that they are the most prevalently used IP-mode in Korea. Overall, industry-university knowledge transfer is more active than industry-PRI knowledge transfer through both IP and non-IP modes.

Now, let me examine the modes of knowledge transfer from PROs, by sector. In each mode of knowledge transfer from universities, a larger number of firms belong to the high-tech industries with a higher score of evaluation than in the other industries (Table 2-1). In the sectors of automobile, chemistry, machinery, and electronics, over 50% of firms receive knowledge through non-IP modes: informal activity, education (except machinery and electronics), and R&D cooperation. In the case of IP modes, 30-40% of firms receive knowledge through patent and licensing and 20-30% through entrepreneurial university. Sector difference is not distinct in business activity, however.

TABLE 1
MODES OF KNOWLEDGE TRANSFER FROM PROs

	Universities		PRIs	
	No. of firms (no=398)	Degree of importance	No. of firms (no=398)	Degree of importance
INFORMAL ACTIVITY	249 (62.6)		226 (56.8)	
Publications/Reports	162 (40.7)	55.25	173 (43.5)	56.25
Conferences/Seminars	162 (40.7)	56.75	155 (38.9)	57.50
Information Exchange	173 (43.5)	57.25	146 (36.7)	58.75
Consulting	191 (48.0)	61.50	164 (41.2)	60.25
EDUCATION	185 (46.5)		144 (36.2)	
Recently hired graduates	120 (30.2)	61.75	96 (24.1)	59.50
Irregular personal exchange	143 (35.9)	57.00	111 (27.9)	59.00
R&D COOPERATION	207 (52.0)		158 (39.7)	
Contract R&D	174 (43.7)	66.50	131 (32.9)	65.25
Joint R&D	181 (45.5)	66.00	134 (33.7)	65.50
R&D networks (*e.g.,* R&D consortium)	124 (31.2)	57.50	97 (24.4)	57.75
PATENT/LICENSING	140 (35.2)		134 (33.7)	
Patents	102 (25.6)	55.50	111 (27.9)	55.75
Licenses	99 (24.9)	58.00	89 (22.4)	56.75
BUSINESS ACTIVITY	85 (21.4)		47 (11.8)	
Technology incubators	67 (16.8)	54.75	37 (9.3)	54.00
Technology parks	61 (15.3)	59.00	41 (10.3)	55.00
Spin-offs	50 (12.6)	54.50	34 (8.5)	56.00
University/PRI-run enterprises	37 (9.3)	57.50	29 (7.3)	56.00

Note: A point on the 7-point Likert scale is converted to a 100-point scale.

Regarding PRIs, over 50% of firms receive knowledge through informal activity in the sectors of automobile, chemistry, machinery, and electronics (Table 2-2). However, in the case of education and R&D cooperation, only firms in the automobile and chemistry sectors are active. Among the IP modes, 48.6% of firms in the automobile and 49.3% in the chemistry sectors use licensing. However, sector difference is not distinct in business activity as in the case of universities.

These results reflect the current state of Korea, that is, industry-PRO interactions are active mainly in specific industries, for example, IT and automobiles, but not comprehensively (Yun 2003).

A large part of knowledge from PROs is transferred without being

TABLE 2-1
MODES OF KNOWLEDGE TRANSFER FROM UNIVERSITIES, BY SECTOR

	INFORMAL ACTIVITY	(1)	(2)	(3)	(4)	EDUCA-TOIN	(5)	(6)	R&D COOPE-RATION	(7)	(8)	(9)
Automobiles	32(91.4)	16	23	21	26	24(68.6)	14	18	29(82.9)	25	26	20
Chemistry	48(71.6)	34	35	34	35	35(52.2)	26	26	40(59.7)	33	36	25
Machinery	38(70.4)	22	21	27	30	24(42.1)	16	17	31(54.4)	27	27	16
Electronics	51(58.6)	43	38	39	39	42(48.3)	28	32	44(50.6)	37	38	31
Food	19(67.9)	12	10	13	15	17(60.7)	13	14	11(39.3)	10	10	7
Textiles	13(61.9)	9	8	8	9	8(38.1)	5	6	8(38.1)	7	7	5
Wood	8(47.1)	5	7	5	6	5(29.4)	3	4	5(29.4)	5	3	1
Rubber	9(39.1)	7	3	8	9	5(21.7)	3	7	9(39.1)	6	9	5
Non-metal products	4(44.4)	4	4	3	3	4(44.4)	4	3	4(44.4)	3	3	3
Metal products	20(46.5)	9	12	14	15	16(37.2)	7	14	21(48.8)	17	18	9
NEC	4(36.4)	2	1	1	1	3(27.3)	1	1	5(45.5)	4	2	2

	PATENT/ LICENSING	(10)	(11)	BUSINESS ACTIVITY	(12)	(13)	(14)	(15)
Automobiles	15(42.9)	11	12	4(11.4)	8	10	4	3
Chemistry	33(49.3)	25	22	10(14.9)	10	8	10	6
Machinery	18(31.6)	13	12	7(12.3)	9	10	7	3
Electronics	32(36.8)	23	22	15(17.2)	23	17	14	11
Food	12(42.9)	7	10	2 (7.1)	4	2	2	2
Textiles	8(38.1)	4	7	4 (1.9)	4	3	4	4
Wood	4(23.5)	4	2	1 (5.8)	0	0	1	0
Rubber	4(17.4)	3	3	4(17.4)	4	4	4	4
Non-metal products	4(44.4)	4	3	1(11.1)	0	1	1	1
Metal products	8(18.6)	6	5	3 (7.0)	5	6	3	3
NEC	2(18.2)	4	4	0 (0.0)	0	0	0	0

Notes: (1) Publications or reports (2) Conferences or seminars (3) Information exchange (4) Consulting (5) Recently hired graduates (6) Irregular personal exchange (7) Patents (8) Licenses (9) Contract R&D (10) Joint R&D (11) Networks to university (*e.g.,* R&D consortium) (12) Technology Incubators (13) Technology parks (14) Spin-offs (15) University-run enterprises.

patented, as the MOCIE (2007) mentions: know-how and some types other than patents, designs, and trademarks, accounted for about 40% of the total technology transferred in 2006. Case studies conducted by Lim and Lee (2008) also find that much know-how or technology has been shared or transferred to firms in the process of cooperative R&D. Bearing in mind this aspect of non-patented technology, it is useful to look into joint R&D and technical assistance in detail.

In the *Survey*, firms were asked to report the performance of joint

TABLE 2-2
MODES OF KNOWLEDGE TRANSFER FROM PRIs, BY SECTOR

	INFORMAL ACTIVITY	(1)	(2)	(3)	(4)	EDUCA-TOIN	(5)	(6)	R&D COOPERA-TION	(7)	(8)	(9)
Automobiles	26(74.3)	20	15	18	21	19(54.3)	13	15	21(60.0)	17	18	14
Chemistry	45(67.2)	35	34	28	31	30(44.8)	15	23	32(47.8)	27	28	17
Machinery	36(63.2)	29	22	19	24	17(29.8)	10	13	21(36.8)	19	19	11
Electronics	51(58.6)	37	38	34	34	34(39.1)	24	25	34(39.1)	26	30	22
Food	13(46.4)	8	10	10	10	11(39.3)	9	9	8(28.6)	7	5	7
Textiles	11(52.4)	9	7	10	9	10(47.6)	7	6	7(33.3)	5	6	5
Wood	8(47.1)	5	6	5	5	3(17.6)	2	3	5(29.4)	5	3	3
Rubber	7(30.4)	8	4	5	7	2 (8.7)	4	6	7(30.4)	5	7	5
Non-metal products	4(44.4)	4	4	4	4	3(33.3)	2	3	4(44.4)	4	3	2
Metal products	23(53.5)	17	14	13	18	10(23.3)	9	8	17(39.5)	14	14	11
NEC	2(18.2)	1	1	1	0	1 (9.1)	1	1	2(18.2)	1	0	0

	PATENT/ LICENSING	(10)	(11)	BUSINESS ACTIVITY	(12)	(13)	(14)	(15)
Automobiles	17(48.6)	14	13	9(25.7)	6	7	3	1
Chemistry	33(49.3)	31	18	6(9.0)	4	5	7	4
Machinery	18(31.6)	13	12	7(12.3)	5	6	4	3
Electronics	29(33.3)	24	18	12(13.8)	10	11	10	8
Food	7(25.0)	5	6	2(7.1)	2	2	2	2
Textiles	5(23.8)	4	3	3(14.3)	3	3	3	4
Wood	3(17.6)	3	2	1(5.9)	1	1	0	1
Rubber	3(13.0)	4	4	2(8.7)	2	2	3	3
Non-metal products	3(33.3)	3	3	2(22.2)	2	1	0	1
Metal products	13(30.2)	9	9	3(7.0)	2	3	2	2
NEC	1(9.1)	1	2	0(0.0)	0	0	0	0

Notes: (1) Publications or reports (2) Conferences or seminars (3) Information exchange (4) Consulting (5) Recently hired graduates (6) Irregular personal exchange (7) Patents (8) Licenses (9) Contract R&D (10) Joint R&D (11) Networks to PRI (*e.g.*, R&D consortium) (12) Technology Incubators (13) Technology parks (14) Spin-offs (15) PRI-run enterprises.

R&D and technical assistance from PROs, respectively, and evaluate their impact on innovation indicators in a 7-point Likert scale (Table 3). The results show that firms conduct cooperative R&D with PROs for new product/process development (243 with universities *vs.* 148 with PRIs) the most, followed by basic/applied technology development (188 *vs.* 73) and existing product/process development (137 *vs.* 64). In addition, firms receive technical assistance from them mostly through technical training/consulting, equipment utilization, and testing/certification services. Noticeably, however, they are dependent more on universities for technical training/consulting (378) and equipment utilization (286), and more on PRIs for equipment utilization (408) and testing/certification service (266).

Regarding the impact of cooperative R&D and technical assistance, firms rate both the corporate and product competitiveness increase high at 66.21 and 60.20 points, respectively (Table 4). In the case of PRIs, they score 58.77 points on the IPR increase. This shows that the non-patented technology from PROs also matters, particularly, in terms of the competitiveness of Korean firms. Overall, firms' evaluation is slightly higher for PRIs than for universities, except employment increase.

IV. Empirical Analysis

A. Hypotheses

The R&D of universities is characterized as core or basic but not practical. Thus, its research output cannot be easily transferred through reverse engineering, which is often used by firms for product or process development. Rather, they are diffused through publications, graduates, informal contacts, and so on. Cohen *et al.* (2002) underline publications and patents as the important ways of knowledge transfer for innovation Zucker *et al.* (2002) consider graduate employment as the effective channel of knowledge transfer and Meyer-Krahmer and Schmoch (1998), cooperative research as the most prevalent form of it.

A university's R&D is also characterized as new or creative. As Tether (2002) points out, industry-university cooperation is appropriate or essential for innovating firms that are in pursuit of new technology. Monjon and Waelbroeck (2003), using CIS data of 1,460 French firms, prove the contribution of this cooperation to radical innovation, that is, being new not only to the firm but also to the market. These arguments imply a higher possibility of these relationships leading to more patents. George *et al.* (2002), based on data of 147 U.S. public-traded biotech companies, find that Research-I university linkage or total federal funding helps firms generate more sales as well as patents. Regarding the informal forms of knowledge transfer from universities, Arvantinis *et al.* (2008), using data of 2,533 Swiss firms, reveal that employing graduates, informal contacts, and R&D cooperation/consortium contribute to the number of patents filed and sales of firms. However, empirical analyses on science parks or entrepreneurial universities are few, as relevant studies focus mainly on theory.

TABLE 3
PERFORMANCE OF COOPERATIVE R&D AND TECHNICAL ASSISTANCE FROM PROs

		Universities		PRIs	
		No. of firms	No. of cooperative R&D and technical assistance	No. of firms	No. of cooperative R&D and technical assistance
Cooperative R&D	Basic/Applied technology development	75 (18.8)	188	34 (8.5)	73
	New product/Process development	95 (23.9)	243	56 (14.1)	148
	Existing product/Process development	60 (15.1)	137	31 (7.8)	64
Technical assistance	Testing/Certification service	45 (11.3)	141	47 (11.8)	266
	Equipment utilization	65 (16.3)	286	67 (16.8)	408
	Prototype	36 (9.0)	103	21 (5.3)	49
	Technical training/Consulting	103 (25.9)	378	72 (18.1)	195
	Education	34 (8.5)	78	24 (6.0)	108

TABLE 4
EVALUATION OF COOPERATIVE R&D AND TECHNICAL ASSISTANCE FROM PROs

Performance	Universities	PRIs
Employment increase	48.33	47.91
IPRs increase	56.06	58.77
Sale increase	54.91	56.63
Cost reduction	52.34	56.20
Corporate competitiveness increase	65.64	66.21
Product competitiveness increase	59.35	60.20

Note: A point on a 7-point likert is converted to on a 100 point likert.

Considering the Korean situation where knowledge industrialization systems have not been well developed, firms may prefer non-IP modes to IP modes of knowledge transfer from PROs, and patent/licenses to science parks or entrepreneurial universities. Moreover, the impact of the modes of the transfer may reveal as patent rather than sales. Based on the above discussions, our first and second hypotheses are as follows:

Hypothesis 1:
All modes of knowledge transfer from PROs, except business activity, may increase the innovation probability of Korean firms.

Hypothesis 2:
All modes of knowledge transfer from PROs, except business activity, may lead to more patents filed but not sales.

Firm heterogeneity in the choice and performance "by sector" is emphasized in much literature. They explain this in terms of characteristics and accessibility to the university's knowledge. Meyer-Krahmer and Schmoch (1998) argue that industry-university interactions matter for science-based industries. Pavitt (1984) also suggests the similar view such that learning from advancements in technology is crucial for science-based industries, *e.g.,* electronics and chemicals, for which industry-university should be more important. Some literature underlines the fact that specific forms of knowledge transfer from university have the importance in specific industries or R&D activities. Cohen *et al.* (2002) and Bekkers and Freitas (2008) argue that publications, conferences, informal contacts and consulting are "widely important" across industries; patents are "only important" for the pharmaceuticals; co-operative research is "at least important" in R&D-based industries. As for electronics, Balconi and Laboranti (2006) argue that the influx of students into firms is the most important for knowledge transfer. However, the empirical evidence in the sector impacts of knowledge transfer from PROs is weak. Based on the above discussions, our third hypothesis is as follows.

Hypothesis 3:
All modes of knowledge transfer from PROs may lead to more patents and sales in the high-tech industries.

B. Model Specifications

This paper analyzes the impact of the modes of knowledge transfer on three aspects: innovation probability ($INNO_{PROB}$), patent ($INNO_{PATENT}$), and sales ($INNO_{SALE}$) of firms. First, this study estimates the impact of the modes on innovation probability using the Probit model. The Survey asked firms how many product innovation and process innovation they conducted respectively during 2004-2006. The dependent variable is 1 if they conducted each innovation more than once and 0 otherwise.

$$f(y\ x_i)=[\Phi(x_i\theta)]^y\ [1-\Phi(x_i\theta)]^{1-y},\quad y=0,\ 1$$

Second, this paper estimates the impact of the modes on patents filed using the *Negative binominal model*. The number of patents is a count data including 0 and positive numbers, and the *Poisson model* is basically appropriate. However, due to the over-dispersion problem, this uses the *Negative binominal model* (Hilbe 2007). The Survey asked firms how many patents they filed during the same period, which is used as the dependent variable.

$$f(y\ x_i)=\exp[-\mu(x_i)]\{\mu(x_i)\}^y/y,\quad y=0,\ 1,\ 2,\ ...$$

Third, this study estimates the impact of the modes on sales using the *OLS*. For this, the log value of sales in 2006 is used as the dependent variable.

The models are specified by firm size, R&D intensity, affiliation to business groups, firm age, export, and sector, as well as the modes of knowledge transfer.

The modes of knowledge transfer (*KT*) are measured as 1 if the firm uses a specific mode of knowledge transfer from PROs and 0 otherwise. Firm size (*SIZE*) is measured as a log value of employees: the larger the firm, the more active the firm is in technological innovation based on its internal resources (Shumpeter 1942). The firm may be faced with difficulties in innovation due to its organizational or managerial inefficiency (Sung 2005). R&D intensity (*RD_INT*) is measured as a ratio of R&D expenditures in sales: the more the R&D investment, the higher the innovation performance is based on the firm's R&D capacity. The impact of the investments on innovation may be invisible if it lags behind (Mohnen and Hoareau 2003). Affiliation to business groups (*GROUP*) is measured as 1 if the firm belongs to groups and 0 otherwise: an affiliate can be an innovator benefiting from its mother firm in terms of financial or technological support (Chang and Hong 2000). Firm age (*AGE*) is measured as a log value of the firm age: the younger the firm, the more active the firm is in technological innovation.

TABLE 5

IMPACTS OF THE MODES OF KNOWLEDGE TRANSFER FROM PROs ON FIRM PERFORMANCE: INNOVATION PROBABILITY (PROBIT MODEL)

	Product innovation									
	Knowledge transfer from university					Knowledge transfer from PRI				
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 1	Model 2	Model 3	Model 4	Model 5
SIZE	0.31	0.31	0.29	0.32	0.34	0.33	0.35	0.34	0.29	0.35
	(2.93)***	(2.93)***	(2.66)***	(3.04)***	(3.22)***	(3.04)***	(3.17)***	(3.11)***	(2.73)***	(3.27)***
RD_INT	0.05	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06
	(1.88)*	(2.04)**	(2.02)**	(2.11)**	(2.09)**	(2.08)**	(2.25)**	(2.21)**	(2.06)**	(2.24)**
GROUP	-0.39	-0.39	-0.45	-0.33	-0.33	-0.33	-0.32	-0.33	-0.35	-0.32
	(-1.37)	(-1.37)	(-1.55)	(-1.18)	(-1.18)	(-1.18)	(-1.16)	(-1.17)	(-1.23)	(-1.16)
AGE	0.15	0.17	0.19	0.17	0.16	0.16	0.15	0.16	0.19	0.16
	(0.97)	(1.09)	(1.12)	(1.09)	(1.05)	(1.05)	(0.98)	(1.01)	(1.22)	(0.99)
EXPORT	0.01	0.02	0.01	0.06	0.08	0.07	0.08	0.08	0.11	0.08
	(0.03)	(0.09)	(0.03)	(0.24)	(0.32)	(0.29)	(0.35)	(0.34)	(0.44)	(0.33)
INFORMAL	0.45					0.14				
	(2.02)**					(0.61)				
EDUCATION		0.45					-0.03			
		(1.88)*					(-0.12)			
RD COOP			0.76					0.03		
			(2.92)***					(0.12)		
LICENSING				0.29					0.73	
				(1.14)					(2.29)**	
BUSINESS					0.11					0.02
					(0.41)					(0.05)
HT	0.32	0.28	0.27	0.30	0.29	0.30	0.30	0.30	0.19	0.30
	(1.08)	(0.92)	(0.89)	(0.99)	(0.97)	(1.00)	(1.01)	(1.00)	(0.61)	(1.01)
MHT	0.20	0.23	0.14	0.24	0.20	0.20	0.21	0.21	0.15	0.21
	(0.68)	(0.76)	(0.46)	(0.81)	(0.68)	(0.68)	(0.72)	(0.71)	(0.50)	(0.71)
MLT	0.27	0.21	0.18	0.22	0.16	0.18	0.16	0.16	0.10	0.16
	(0.86)	(0.67)	(0.58)	(0.71)	(0.52)	(0.58)	(0.53)	(0.54)	(0.32)	(0.54)
_cons	-0.93	-0.90	-0.87	-0.90	-0.93	-0.91	-0.93	-0.92	-0.87	-0.93
	(-1.69)*	(-1.64)	(-1.54)	(-1.71)	(-1.70)*	(-1.68)*	(-1.70)*	(-1.68)*	(-1.57)	(-1.70)*
No. of obs	374	374	374	374	374	374	374	374	374	374
LR^2	31.2	30.8	36.8	28.4	35.9	27.1	30.6	27	33.5	27.03
Pse R^2	0.15	0.15	0.18	0.14	0.18	0.13	0.13	0.13	0.16	0.13
LL	-84.42	-86.61	-83.59	-88.4	-84.05	-88.3	-88.47	-88.51	-85.27	-88.48

(Table 5 Continued)

Export (*EXPORT*) is measured as 1 if the firm exported during 2004-2006 and 0 otherwise: the more open (to global competition) the firm, the more active the firm is in technological innovation. Sector (*SECTOR*) is measured in four ways: high-tech industries (*HT*), medium high-tech industries (*MHT*), medium low-tech industries (*MLT*), and low tech-industries (*LT*). They follow the OECD classification, which is based

TABLE 5
(CONTINUED)

	Process innovation									
	Knowledge transfer from university					Knowledge transfer from PRI				
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 1	Model 2	Model 3	Model 4	Model 5
SIZE	0.11	0.099	0.01	0.11	0.12	0.104	0.09	0.099	0.11	0.13
	(1.59)	(1.48)	(1.51)	(1.65)	(1.87)*	(1.54)	(1.32)	(1.48)	(1.56)	(1.89)*
RD_INT	-1.37	-1.50	-0.01	-1.44	-1.33	-1.44	-1.46	-1.50	-1.25	-1.18
	(-0.84)	(-0.92)	(-0.90)	(-0.88)	(-0.82)	(-0.89)	(-0.89)	(-0.92)	(-0.77)	(-0.73)
GROUP	-0.22	-0.22	-0.19	-0.16	-0.17	-0.19	-0.18	-0.22	-0.18	-0.17
	(-1.08)	(-1.08)	(-0.95)	(-0.81)	(-0.86)	(-0.93)	(-0.90)	(-1.08)	(-0.91)	(-0.85)
AGE	-0.08	-0.06	-0.07	-0.05	-0.05	-0.07	-0.05	-0.06	-0.06	-0.05
	(-0.71)	(-0.58)	(-0.65)	(-0.51)	(-0.50)	(-0.65)	(-0.44)	(-0.58)	(-0.52)	(-0.51)
EXPORT	-0.03	-0.03	-0.02	0.01	0.02	0.00	-0.01	-0.03	0.03	0.02
	(-0.18)	(-0.16)	(-0.11)	(0.06)	(0.14)	(0.01)	(-0.04)	(-0.16)	(0.20)	(().12)
INFORMAL	0.47					0.35				
	(3.10)***					(2.31)**				
EDUCATION		0.52					0.43			
		(3.43)***					(2.64)***			
RD COOP			0.38					0.52		
			(2.56)**					(3.43)***		
LICENSING				0.34					0.31	
				(2.14)**					(1.88)*	
BUSINESS					0.22					0.18
					(1.22)					(1.20)
HT	0.39	0.37	0.37	0.39	0.39	0.37	0.40	0.37	0.35	0.41
	(1.87)*	(1.77)*	(1.78)*	(1.88)*	(1.85)*	(1.77)*	(1.91)*	(1.77)*	(1.66)	(1.98)**
MHT	0.34	0.40	0.33	0.41	0.36	0.33	0.40	0.40	0.36	0.38
	(1.66)	(1.93)*	(1.62)	(2.01)**	(1.74)*	(1.60)	(1.94)*	(1.93)*	(1.74)*	(1.86)*
MLT	0.57	0.54	0.49	0.547	0.47	0.49	0.52	0.54	0.46	0.49
	(2.49)**	(2.40)**	(2.18)**	(2.42)**	(2.11)**	(2.18)**	(2.32)**	(2.40)**	(2.05)**	(2.19)**
_cons	-0.17	-0.11	-0.11	-0.13	-0.12	-0.08	-0.06	-0.11	-0.07	-0.13
	(-0.44)	(-0.28)	(-0.28)	(-0.35)	(-0.32)	(-0.21)	(-0.16)	(-0.28)	(-0.18)	(-0.33)
No. of obs	374	374	374	374	374	374	374	374	374	374
LR^2	22.1	24.5	19.1	17.0	13.9	17.8	19.6	14.9	16	13.4
Pse R^2	0.05	0.06	0.04	0.04	0.03	0.04	0.05	0.03	0.04	0.03
LL	-206.1	-204.9	-207.6	-208.6	-210.2	-208.3	-207.4	-209.7	-209.1	-210.5

on R&D intensity. The variable is 1 if the firm belongs to a specific technology group and 0 otherwise.

C Empirical Results

a) Product Innovation Versus Process Innovation

This part examines how the different modes of knowledge transfer from PROs affect the innovation probability of firms using the *Probit model*. The dependent variable is 1 if a firm conducts product innovation and process innovation, respectively, and 0 otherwise.

The left two columns of Table 6 present the results on the impact of the modes of knowledge transfer on product innovation. In the case of universities, the coefficients of *INFORMAL*, *EDUCATION*, and *R&D COOP* are statistically significant, implying that non-IP modes of knowledge transfer facilitate the product innovation of firms. On the other hand, the coefficients of *LICENSING* and *BUSINESS* are not statistically significant, which means there is no significant impact of IP modes of the transfer on the innovation probability. In the case of PRIs, only the coefficient of LICENSING is statistically significant, while those of *INFORMAL, EDUCATION, R&D COOP,* and *BUSINESS* are not. This means that patent/licenses matter for this innovation, while technology incubators/parks, spin-offs, and entrepreneurial universities/PRIs as well as non-IP modes of the transfer do not. It is noticeable that patent/licensing proves to be a determinant of product innovation only in the case of knowledge transfer from PRIs, which reflects the Korean case wherein technology is transferred to firms from PRIs more than universities, although the increase in the transfer of the universities has been faster than that of the PRIs recently.

Among other variables, *SIZE* and *RD_INT* are statistically significant, implying that aside from external knowledge, firm size and R&D intensity contribute to the product innovation of firms. However, affiliation to business group (*GROUP*), firm age (*AGE*), and sector characteristics (*HT, MHT,* and *MLT*) are not found to be determinants of innovation.

The right two columns of Table 6 present the results on the impact of the modes of knowledge transfer on process innovation. In the case of universities, the coefficients of *INFORMAL, EDUCATION, R&D COOP,* and *LICENSING* are statistically significant, while that of *BUSINESS* is not. This implies that all modes of knowledge transfer, except *BUSINESS*, facilitate the process innovation of firms. In the case of PRIs, the coefficients of *INFORMAL, EDUCATION, R&D COOP,* and *LICENSING*, except *BUSINESS*, are also statistically significant. Unlike the case of product innovation, all modes of knowledge transfer, except *BUSINESS*, are determinants of process innovation.

Unlike the case of product innovation, *SIZE* and *RD_INT* are not found to be significant in this innovation, which implies that firms depend on external knowledge rather than internal resources or other firm characteristics, affiliation to business group (*GROUP*), and firm age (*AGE*) for process innovation. Sector characteristics (*HT, MHT,* and

MLT), however, are significant in this case.

b) Patents versus Sales

This part examines how the different modes of knowledge transfer from PROs affect the patents and sales of firms (Table 6). The Negative binominal model is used for the count data of patents filed and the OLS for sales.

The left-half side of the table presents the results on the impacts of the modes of knowledge transfer from PROs on the number of patents filed. The coefficients of *INFORMAL, EDUCATION, R&D COOP*, and *LICENSING* are significantly positive, implying that these four modes serve firms with new knowledge, eventually to raise the number of patents filed by the firms. On the other hand, the coefficient of *BUSINESS* is not statistically significant, which means it has no significant contribution to the patent-filing. As expected, non-IP modes of knowledge transfer and only patent/licenses among the IP modes positively affect the firms' patent-filing, while technology incubators/parks, spin-offs, and entrepreneurial universities/PRIs, as recently developed tools, do not.

On the other hand, in case of sales, no significantly positive sign is found in any mode of knowledge transfer as seen on the right-half side of Table 6. As expected, neither IP modes nor non-IP modes of transfer have contributions to sales; even patent/licensing and business activity (technology incubators/parks, spin-offs, and entrepreneurial universities/PRIs) cannot affect the industrialization of firms' technology.

Based on the above, we can conclude that patent/licensing and non-IP modes of transfer from PROs facilitate Korean firms' innovation by creating new knowledge in the form of patents, but they still have limitations in industrializing knowledge in the form of sales. This is consistent with the empirical result of Eom and Lee (2008), which explains this phenomenon in terms of the level of developments in knowledge industrialization systems; that is, the system in Korea is underdeveloped, and thus the impact of interactions with PROs is revealed as patents. In addition, she differentiates the Korean case from that of developed countries, whose systems have been well-developed, thus revealing their impact on sales as well as patents.

Among other variables, the *SIZE* variable is significantly positive for both patents and sales, suggesting that larger firms tend to be more innovative than smaller ones. On the other hand, *RD_INT* is significantly positive only for patents but not for sales, which may be due to

TABLE 6
IMPACTS OF THE MODES OF KNOWLEDGE TRANSFER FROM PROs ON FIRM PERFORMANCE: PATENTS vs. SALES

	Patents									
	Knowledge transfer from university					Knowledge transfer from PRI				
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 1	Model 2	Model 3	Model 4	Model 5
SIZE	0.89 (9.21)***	0.88 (9.38)***	0.89 (9.83)***	0.93 (9.91)***	0.98 10.41)***	0.91 (9.79)***	0.83 (8.72)***	0.93 (9.93)***	0.92 (9.83)***	0.98 (10.41)***
RD_INT	0.09 (2.74)***	0.09 (2.69)***	0.09 (3.06)***	0.10 (3.00)***	0.11 (3.56)***	0.10 (3.05)***	0.07 (2.38)**	0.10 (3.09)***	0.10 (3.08)***	0.12 (3.52)***
GROUP	-0.31 (-0.99)	-0.3 (-0.94)	-0.41 (-1.34)	-0.33 (-1.03)	-0.25 (-0.74)	-0.22 (-0.68)	-0.36 (-1.15)	-0.32 (-1.02)	-0.31 (-1.00)	-0.27 (-0.84)
AGE	0.07 (0.40)	0.12 (0.72)	0.05 (0.28)	0.04 (0.26)	0.06 (0.37)	0.07 (0.40)	0.14 (0.84)	0.02 (0.13)	0.01 (0.09)	0.07 (0.38)
EXPORT	0.29 (0.98)	0.28 (0.94)	0.32 (1.08)	0.36 (1.21)	0.35 (1.15)	0.35 (1.18)	0.29 (1.02)	0.36 (1.21)	0.45 (1.51)	0.36 (1.19)
INFORMAL	0.64 (2.70)***					0.62 (2.80)***				
EDUCATION		0.71 (3.19)***					0.90 (3.85)***			
RD COOP			0.75 (3.61)***					0.46 (2.01)**		
LICENSING				0.47 (1.98)**					0.64 (2.66)***	
BUSINESS					-0.12 (-0.46)					-0.13 (-0.43)
HT	1.16 (3.70)***	0.92 (2.90)***	1.10 (3.47)***	1.03 (3.24)***	1.11 (3.40)***	0.96 (2.99)***	0.83 (2.64)***	0.98 (3.05)***	0.88 (2.71)***	1.10 (3.37)***
MHT	0.801 (2.55)**	0.71 (2.26)**	0.74 (2.36)**]	0.89 (2.76)***	0.79 (2.44)**	0.64 (1.99)**	0.68 (2.20)**	0.78 (2.44)**	0.79 -2.48	0.78 (2.42)**
MLT	0.58 (1.70)*	0.47 (1.39)	0.51 (1.48)	0.56 (1.64)	0.6 (1.70)*	0.38 (1.08)	0.41 (1.21)	0.45 (1.30)	0.36 (1.02)	0.6 (1.69)*
_cons	-4.69 (-7.66)***	-4.58 (-7.54)***	-4.63 (-7.67)***	-4.66 (-7.53)***	-4.89 (-7.78)***	-4.71 (-7.72)***	-4.33 (-7.12)***	-4.54 (-7.22)***	-4.51 (-7.32)***	-4.82 (-7.82)***
No. of obs	374	374	374	374	374	374	374	374	374	374
LR^2	198.9	202	204.5	196.2	192.4	199.6	206.7	196.3	199.4	102.4
Pse R^2	0.10	0.10	0.11	0.10	0.10	0.10	0.11	0.10	0.10	0.10
LL	-876.4	-874.9	-874.6	-877.8	-879.7	-874.1	-872.5	-877.8	-876.2	-879.7

(Table 6 Continued)

the short period of this analysis such that the impact of in-house R&D has not been fully revealed to increase firms' sales. Firm age (*AGE*) is significant only in the case of sales, while sector characteristics (*HT*, *MHT*, and *MLT*) are significant only in the case of patents. However, neither *GROUP* nor *EXPORT* is significant to these innovation outcomes.

TABLE 6
(CONTINUED)

	Sales									
	Knowledge transfer from university					Knowledge transfer from PRI				
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 1	Model 2	Model 3	Model 4	Model 5
SIZE	1.12 (25.65)***	1.13 (25.71)***	1.12 (25.44)***	1.13 (25.79)***	1.12 (25.73)***	1.13 25.6)***	1.11 (24.86)***	1.12 (25.26)***	1.13 (25.46)***	1.12 (25.8)***
RD_INT	-0.02 (-2.19)**	-0.02 (-2.15)**	-2.44 (-2.19)**	-0.02 (-2.03)**	-2.36 (-2.11)**	-0.02 (-2.10)**	-0.03 (-2.27)**	-0.02 (-2.19)**	-0.02 (-2.16)**	-0.02 (-2.16)**
GROUP	0.19 (1.39)	0.19 (1.41)	0.19 (1.37)	0.18 (1.35)	0.18 (1.36)	0.18 (1.37)	0.18 (1.34)	0.18 (1.36)	0.19 (1.37)	0.18 (1.34)
AGE	0.13 (1.91)*	0.13 (1.87)*	0.13 (1.87)*	0.12 (1.75)*	0.12 (1.77)*	0.13 (1.88)*	0.13 (1.89)*	0.12 (1.86)*	0.12 (1.78)*	0.11 (1.69)*
EXPORT	0.11 (0.96)	0.12 (1.02)	0.11 (0.92)	0.11 (0.98)	0.10 (0.90)	0.11 (0.98)	0.09 (0.82)	0.10 (0.88)	0.10 (0.87)	0.11 (0.98)
INFORMAL	-0.1 (-0.97)					-0.14 (-1.47)				
EDUCA- TION		-0.14 (-1.45)					0.04 -0.42			
RD COOP			-0.06 (-0.57)					-0.05 (-0.54)		
LICENSING				-0.13 (-1.37)					-0.12 (-1.18)	
BUSINESS					-0.1 (-0.92)					-0.18 (-1.28)
HT	0.17 (1.21)	0.18 (1.28)	0.17 (1.22)	0.18 (1.29)	0.18 (1.29)	0.18 (1.31)	0.16 (1.15)	0.17 (1.22)	0.19 (1.35)	0.17 (1.25)
MHT	0.10 (0.75)	0.10 (0.71)	0.10 (0.74)	0.08 (0.60)	0.11 (0.77)	0.12 (0.86)	0.09 (0.67)	0.1 (0.72)	0.11 (0.77)	0.1 (0.73
MLT	0.25 (1.65)	0.25 (1.68)*	0.26 (1.75)*	0.24 (1.59)	0.27 (1.80)*	0.26 (1.78)*	0.26 (1.75)*	0.27 (1.77)*	0.27 (1.83)*	0.26 (1.77)*
_cons	4.40 (17.15)***	4.39 (17.12)***	4.38 (17.05)***	4.40 (17.21)***	4.40 (17.13)***	4.38 (17.1)***	4.40 (17.09)***	4.38 (17.00)***	4.38 (17.06)***	4.41 (17.18)***
No. of obs	374	374	374	374	374	374	374	374	374	374
LR^2	104.7	105.1	104.4	105.5	104.6	105.1	104.4	104.4	104.8	104.9
Pse R^2	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
LL	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71

c) Sector Heterogeneity

Finally, this part examines how the different modes of knowledge transfer from PROs affect firm performance by sector. The models used for this analysis are the same as those used in the previous analysis (Table 7). The left two parts presents the results on the impact of the modes of knowledge transfer from PROs on (patents).

The coefficient of the interaction terms of *INFOMAL* (in case of universities) and *INFORMAL, EDUCATION* and *R&D COOP* (in case of

TABLE 7
IMPACTS OF THE MODES OF KNOWLEDGE TRANSFER FROM PROs ON FIRM PERFORMANCE: SECTOR HETEROGENEITY

	Patents									
	Knowledge transfer from university					Knowledge transfer from PRI				
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 1	Model 2	Model 3	Model 4	Model 5
SIZE	0.9	0.83	0.89	0.89	1	0.89	0.78	0.87	0.88	0.98
	(9.08)***	(8.88)***	(9.71)***	(9.71)***	(10.56)***	(9.42)***	(8.49)***	(9.57)***	(9.86)***	(10.45)***
RD_INT	0.09	0.08	0.09	0.09	0.12	0.09	7.3	0.09	0.09	0.1
	(2.75)***	(2.52)**	(3.00)***	(3.00)***	(3.78)***	(2.88)***	(2.33)**	(3.02)***	(2.97)***	(3.18)***
GROUP	-0.36	-0.24	-0.42	-0.42	-0.23	-0.22	-0.34	-0.26	-0.13	-0.19
	(-1.15)	(-0.77)	(-1.35)	(-1.35)	(-0.69)	(-0.70)	(-1.11)	(-0.83)	(-0.44)	(-0.58)
AGE	0.04	0.07	0.00	0.00	0.00	0.00	0.05	-0.03	-0.01	0.00
	(0.21)	(0.41)	(0.02)	(0.02)	(0.02)	(0.01)	(0.28)	(-0.17)	(-0.08)	(0.01)
EXPORT	0.32	0.31	0.32	0.32	0.33	0.53	0.29	0.53	0.64	0.48
	(1.06)	(1.07)	(1.08)	(1.08)	(1.11)	(1.78)*	(1.04)	(1.82)*	(2.29)**	(1.60)
INFORMAL	0.81					-0.13				
	(1.55)					(-0.26)				
EDUCATION		-0.15					-0.35			
		(-0.30)					(-0.70)			
RD COOP			1.00					0.17		
			(1.95)*					(0.30)		
LICENSING				1.00					0.19	
				(1.95)*					(0.33)	
BUSINESS					0.47					-0.87
					(1.01)					(-0.90)
HT	1.22	0.27	1.14	1.14	1.39	0.38	0.12	0.48	0.45	1.16
	(2.29)**	(0.66)	(2.66)***	(2.66)***	(4.05)***	(0.83)	(0.33)	(1.24)	(1.22)	(3.43)***
MHT	1.19	0.39	0.98	0.98	0.75	0.6	0.36	0.96	0.98	0.74
	(2.14)**	(0.97)	(2.29)**	(2.29)**	(2.22)**	(1.26)	(0.99)	(2.53)**	(2.76)***	(2.20)**
MLT	0.54	0.17	0.59	0.59	0.48	-0.39	0.13	0.23	-0.03	0.34
	(0.99)	(0.41)	(1.29)	(1.29)	(1.35)	(-0.83)	(0.34)	(0.56)	(-0.07)	(0.94)
HT*KT	-0.10	1.48	-0.11	-0.11	-1.12	1.18	2.11	1.16	1.11	0.06
	(-0.14)	(2.30)**	(-0.17)	(-0.17)	(-0.17)	(1.83)*	(3.33)***	(1.66)*	(1.57)	(0.06)
MHT*KT	-0.57	0.87	-0.50	-0.50	-0.34	0.32	1.19	-0.52	-0.71	0.67
	(-0.84)	(1.41)	(-0.80)	(-0.80)	(-0.56)	(0.50)	(1.92)*	(-0.78)	(-1.03)	(0.62)
MLT*KT	0.10	0.81	-0.20	-0.20	-0.20	1.52	1.02	0.63	1.26	1.95
	(0.14)	(1.20)	(-0.29)	(-0.29)	(-0.29)	(2.25)**	(1.50)	(0.88)	(1.66)*	(1.63)
_cons	-4.78	-3.92	-4.61	-4.61	-4.75	-4.21	-3.52	-4.134	-4.34	-4.64
	(-6.36)***	(-5.85)***	(-6.91)***	(-6.91)***	(-7.69)***	(-6.22)***	(-5.43)***	(-6.28)***	(-6.91)***	(-7.50)***
No. of obs	374	374	374	374	374	374	374	374	374	374
LR^2	200.4	202	204.5	196.2	192.4	206.7	206.7	196.3	199.4	102.4
Pse R^2	0.10	0.10	0.11	0.10	0.10	0.11	0.11	0.10	0.10	0.10
LL	-875.7	-874.9	-874.6	-877.8	-879.7	-879.4	-872.5	-877.8	-876.2	-879.7

(Table 7 Continued)

TABLE 7
(CONTINUED)

	Sales									
	Knowledge transfer from university					Knowledge transfer from PRI				
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 1	Model 2	Model 3	Model 4	Model 5
SIZE	1.12 (25.70)***	1.12 (25.80)***	1.12 (25.51)***	1.14 (26.05)***	1.12 (25.66)***	1.12 (25.46)***	1.11 (24.60)***	1.12 (25.00)***	1.13 (25.49)***	1.12 (25.68)***
RD_INT	-0.03 (-2.3)**	-0.03 (-2.38)**	-0.03 (-2.36)**	-0.02 (-2.14)**	-0.02 (-2.12)**	-0.02 (-2.21)**	-0.03 (-2.36)**	-0.03 (-2.24)**	-0.02 (-2.20(**	-0.02 (-2.12)**
GROUP	0.22 (1.62)	0.20 (1.51)	0.16 (1.21)	0.19 (1.40)	0.18 (1.35)	0.21 (1.53)	0.18 (1.35)	0.18 (1.30)	0.2 (1.50)	0.18 (1.35)
AGE	0.13 (1.95)*	0.14 (2.08)**	0.13 (1.96)*	0.10 (1.55)	0.12 (1.79)*	0.13 (2.01)**	0.13 (1.94)*	0.13 (1.87)*	0.12 (1.77)*	0.11 (1.67)
EXPORT	0.12 (1.02)	0.12 (1.06)	0.12 (1.03)	0.10 (0.93)	0.10 (0.89)	0.13 (1.16)	0.09 (0.79)	0.11 (0.98)	0.12 (1.03)	0.11 (0.95)
INFORMAL	-0.32 (-1.46)					-0.19 (-0.89)				
EDUCA-TION		-0.21 (-0.97)					-0.11 (-0.48)			
RD COOP			0.16 (0.72)					0.07 (0.28)		
LICENSING				0.08 (0.37)					0.14 (0.49)	
BUSINESS					-0.07 (-0.31)					-0.21 (-0.55)
HT	-0.19 (-0.84)	-0.07 (-0.35)	0.13 (0.73)	0.12 (0.70)	0.17 (1.14)	0.04 (0.21)	0.04 (0.23)	0.15 (0.87)	0.15 (0.93)	0.17 (1.14)
MHT	0.13 (0.56)	0.20 (1.13)	0.35 (1.86)*	0.30 (1.82)*	0.13 (0.89)	0.32 (1.57)	0.08 (0.48)	0.17 (1.03)	0.26 (1.62)	0.09 (0.61)
MLT	0.11 (0.52)	0.25 (1.35)	0.37 (1.96)*	0.36 (2.10)**	0.26 (1.76)*	0.13 (0.67)	0.21 (1.16)	0.33 (1.87)*	0.32 (1.88)*	0.27 (1.73)*
HT*KT	0.36 (0.95)	0.26 (1.35)	0.01 (0.02)	0.06 (0.20)	0.01 (0.02)	0.25 (0.89)	0.34 (1.17)	0.00 (0.00)	-0.06 (-0.19)	0.05 (0.10)
MHT*KT	0.02 (0.06)	-0.20 (-0.74)	-0.30 (-1.12)	-0.27 (-1.00)	-0.11 (-0.39)	-0.28 (-0.99)	0.06 (0.22)	-0.2 (-0.74)	-0.31 (-1.00)	0.09 (0.20)
MLT*KT	0.24 (0.80)	-0.01 (-0.04)	-0.30 (-0.97)	-0.43 (-1.30)	-0.08 (-0.38)	0.28 (0.93)	0.17 (0.54)	-0.24 (-0.71)	-0.25 (-0.72)	-0.07 (-0.13)
_cons	4.52 (15.76)***	4.39 (16.26)***	4.29 (15.87)***	4.33 (16.37)***	4.39 (16.99)***	4.4 (15.87)***	4.46 (16.56)***	4.34 (15.97)***	4.32 (16.66)***	4.42 (17.01)***
No. of obs	374	374	374	374	374	374	374	374	374	374
LR^2	78	78	78.1	78.1	78.9	78	78	78.1	78.1	78.9
Pse R^2	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
LL	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71

PRIs) with sector dummies (*HT, MHT,* and *MLT*) is statistically positive only in the high-tech industries. This implies that firms in the high-tech industries are more active in creating or receiving new knowledge from PROs through non-IP modes, and perform better than those in other sectors. Chemistry, electronics and computers are the industries whose technology is changing fast, and thus it is crucial the timely acquisition of new knowledge or the influx of new manpower. On the other hand, the coefficient of interaction terms between LICENSING or BUSINESS and the sector dummies is not statistically significant, meaning that patent/licenses, technology incubator/parks, spin-offs or entrepreneurial universities/PRIs has no significant contribution to the patent-filing. In sum, the sector heterogeneity in the impacts of knowledge transfer from PROs are significant only in the high-tech industries, and it is, through non-IP modes.

However, in the case of sales, no significantly positive sign is found in any mode of knowledge transfer even in the high-tech industries, as seen on the right-half part of Table 7. That is, neither IP modes nor non-IP modes of transfer have contributions to these industries; even patent/licensing and business activity (technology incubators/parks, spin-offs, and entrepreneurial universities/PRIs) cannot affect the industrialization of technology.

Based on the above, we can conclude that non-IP modes of knowledge transfer from PROs facilitate Korean firms' innovation, particularly, in the high-tech industries, but that still face limitations in industrializing the knowledge in the form of sales even in these industries.

Other variables such as *SIZE, RD_INT, ALGE, GROUP*, and *EXPORT* maintain their statistical significance as in the previous analysis.

V. Conclusion

Given the increasing importance of knowledge transfer from PROs as a source of new knowledge, this paper investigated the modes of transfer in terms of the Korean NIS. Specifically, this study examined how the different modes of knowledge transfer affect firm performance and how different their impacts are according to sector.

As a fast catching-up economy, the NIS of Korea has been unbalanced or immature, characterized by the strong dominance of the government and a few big firms called *chaebols* along with the weak roles of universities and the SMEs. These unique characteristics have rendered the knowledge industrialization systems of Korea underdeveloped. It is only recently, specifically since the mid-1990s, that Korea has realized the significance of knowledge industrialization and started to promote it again through government initiatives.

This analysis utilizes the *Survey on Korean Industry-University/PRI Relationships* and conceptualizes the modes of knowledge transfer from PROs to estimate their impact on firm performance. Regarding the latter, it has focused on innovation probability, patents, and sales. The three main findings are as follows.

First, non-IP modes of knowledge transfer and patent/licensing from universities facilitate product innovation, while only patent/licensing from PRIs does in the case of product innovation. On the other hand, all modes of knowledge transfer from PROs, except business activity, promote process innovation.

Second, non-IP modes of knowledge transfer and only patent/licensing among the IP-modes facilitate industrial innovation by creating new knowledge through patents, but they still face limitations in industrializing knowledge through sales. On the other hand, business activity is not significant even for patent-filing.

Third, non-IP modes of knowledge transfer facilitate industrial innovation, through the patent-filing, only in the high-tech industries. However, even in these industries they still face limitations in industrializing knowledge through sales.

This analysis suggests several policy implications. First, for product innovation, firms need to develop strategies for utilizing or combining various modes of knowledge transfer from PROs. Second, the Korean government needs to diversify the criteria for evaluating the R&D performance of firms to translate the impact of knowledge transfer modes from PROs into sales. In particular, both firms and PROs consider making research designs for knowledge industrialization at the initial stage of cooperation. Third, keeping in mind the fact that business activity currently has no significant impact on industrial innovation, more support to facilitate spin-offs, science parks, and entrepreneurial university/PRI is needed.

The contribution of this paper is the conceptualization of the modes of knowledge transfer from PROs to analyze the case of Korea as a latecomer in knowledge industrialization. One limitation should be pointed out, however. This analysis could not cover the dynamic role of the modes in industrial innovation because the data used here are cross-sectional. We will keep these data for future work.

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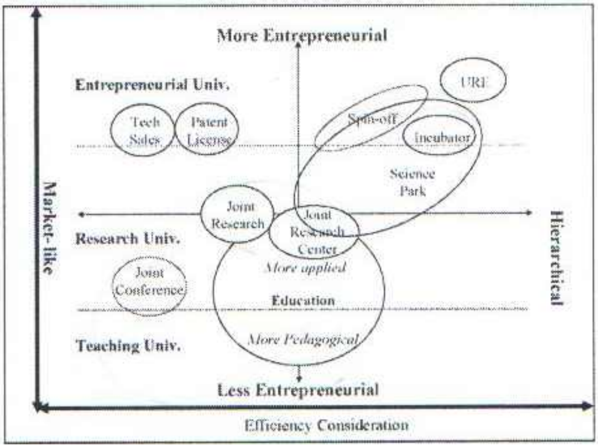
Appendix



Source: Eun *et al.* 2006.

FIGURE A1

GOVERMANCE FORMS OF KNOWLEDGE INDUSTRIALIZATION FROM UNIVERSITY-INDUSTRY LINKAGES

TABLE A1

COMPARISONS IN THE PERFORMANCE OF TECHNOLOGY TRANSFER (AS OF 2005)

	Korea			U.S.			Europe			Japan
	University	PRI	Total	University	PRI	Total	University	PRI	Total	
No. of technology developed	4,156	4,305	8,551	11,413	1,614	13,027	1,375	1,486	2,861	9,400
No. of technology transferred	715	1,358	2,073	4,053	630	4,683	384	955	1,339	1,852
Rate of technology transfer ($hundred millions)	17.2	31.5	24.2	35.5	39.0	35.9	27.9	64.3	46.8	19.7
Royalties from technology transfer	8.0	73.7	81.7	2,600	336	1,936	90	245	335	
R&D expenditure ($hundred millions)	2,387.5	3,178.6	5,566.1	36,662	4,081	40,742	4,264	5,348	9,612	
R&D productivity (%)	0.3	2.3	1.5	4.8	8.2	4.8	2.1	4.5	3.5	

Notes: 1) Korea: A Survey on the Technology Transfer of PROs: 2005 (145 universities and 114 PRIs)
2) U.S.: AUTM U.S. Licensing Survey: FY 2005 (152 universities and 29 PRIs)
3) Europe: ASTP (Association of Europe Science & Technology Transfer Professionals): FY 2004-2005 (22 countries, 74 universities and 27 PRIs)
4) Japan: A Survey on Intellectual Property: FY 2005

Source: MOCIE (2007). A Survey on the Technology Transfer of PROs.

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