Kwon et al. Journal of Open Innovation: Technology, Market, and Complexity (2015) 1:21
DOI 10.1186/s40852-015-0024-6

Journal of Open Innovation: Technology, Market, and Complexity
a SpringerOpen Journal

RESEARCH Open Access

The impact of graduate students on research productivity in Korea

Ki-Seok Kwon[1], Seok Ho Kim[2], Tae-Sik Park[2], Eun Kyoung Kim[2] and Duckhee Jang[3*]

* Correspondence: jdh73@kiost.ac
[3]Korea Institute of Ocean Science & Technology, Gyeonggi-do, South Korea
Full list of author information is available at the end of the article

Abstract

Even though graduate students are critical for carrying out research, they have not been treated as important in the existing literature on research productivity. Accordingly, this paper focuses on whether the number of graduate students has a significant impact on their supervisors' research productivity. In order to address this question, we have collected a large scale data on Korean academics' research performance. According to the results of the analysis, first, male researchers were found to have more graduate students than female researchers. Second, we found significant differences in the total number of graduate students employed by senior and junior researchers. Third, researchers from the capital were also found to manage more graduate students. Last, as we found the number of graduate students to correlate with significant differences in researchers' productivity, we put forward some suggestions for ways to support researchers who are female, young, and located in non-capital areas.

Keywords: The relationship between teaching and research, Academic productivity, Graduate students, Economics of science, South Korea

Background

Universities have expanded their role in society from the preparation of the next generation (i.e., teaching) to the production of novel knowledge (i.e., research); recently, their role has also expanded to include a direct contribution to the economy through its exploitation of the knowledge created. Furthermore, we have noticed a university graduates in open innovation as an important actor for diffusion of tacit knowledge in innovation system (Patra and Krishna, 2015). In light of these changes, Brew (2006) has proposed a new model for the relationship between the first mission (teaching) and the second mission (research). According to Brew, teaching and research need to be integrated to promote synergy between the two missions, i.e., better education through inquiry-based learning. Students' role in universities, particularly relative to their professors, has also changed, making these students not only the recipients of existing knowledge, but also active participants in knowledge generation. In recent years, students (particularly graduate students) have become essential factors for carrying out academic research in universities.

A number of studies have been conducted on the factors that enable successful research. Knowledge of these factors is critical to determining the appropriate allocation of research and development (R&D) resources. Although the most influential factor on research productivity is unquestionably the chief researcher's personal capability, there is still some question about the other influential factors (Hess 1997; Stephan 1996), with different environmental, organizational, and human properties being found to influence research productivity.

The present paper focuses on whether graduate students are an important factor in their supervisors' research productivity, with the assumption that managing more graduate students would allow more research to be conducted. Specifically, Korean academics in regional universities (i.e. universities far from the capital) sometimes report having trouble in continuing their research due to the difficulty of securing graduate students. A continuous stream of graduate students is critical for the operation of university laboratories, as well as for proper career management of graduate students involved in their supervisors' research projects. Further, a strongly unequal distribution of research resources (i.e., graduate students and funding) would, in the long run, negatively affect the knowledge production of the larger academic community.

However, despite the fact that the procurement and utilization of graduate students is critical, this area is underexplored—in large part, due to a lack of empirical evidence. The present study therefore conducted an empirical analysis of the influence of graduate students on research productivity.

The present study obtained data on graduate students from the National Research Foundation of Korea (NRF), which was combined with data about supervisors' individual productivity also from NRF. The data used in the present study are comparable in quantity and quality to previous domestic and foreign research, and are treated with various empirical analyses. The difference analysis was used to explore correlations between the number of graduate students and research productivity according to factors that have been discussed in the existing literature, such as gender, age, and region (i.e., geographical location). Results were produced using regression analysis of graduate students' influences on research productivity.

We had two research questions: first, how differently are graduate students distributed depending on researchers' gender, age, and region? Second, what effects, if any, does the number of graduate students have on researchers' productivity?

Literature review

According to Stephan and Levin (1992), human resources largely determine scientists' productivity; research productivity is a function of research equipment, human resources, and funds. Von Tunzelmann et al. (2003) evaluated the relationship between institutional size and research productivity on the personal, departmental, and institutional level. They found a small positive correlation at the personal level, a very strong positive correlation at the departmental level, and a very small correlation at the institutional level.

There have been a number of studies on the structural characteristics of human resources in academic research, especially on the relationship between graduate students and research productivity. Graduate students have been argued to play the most important role in university research output (Salter et al. 2000), and according to Song (2001), an increase in the number of doctoral students significantly positively correlates with their professors' productivity. Kwon (2010) conducted both an econometric analysis and case studies for each type of Korean university, and found that the university type that retained the most graduate students had higher research and patent productivity. Kwon (2010) also found, through case-study interviews at regional universities, that undergraduate students are often utilized due to a lack of graduate students. Not surprisingly, these undergraduate students report difficulties stemming from the lack of adequate support and the demands for them to work above their capabilities.

According to a regression analysis conducted on the relationship between the number of graduate students and the technology-transfer activities of universities at the university level, the number of graduate students significantly positively correlated with the number of patent applications that universities made (Kwon 2011). At the personal level, having more students in master programs or PhD programs both positively correlated with professors' productivity (Ryu and Pae 1997). However, in the case of post-doctoral fellows, young human resources of research belonged to the professor's laboratory, if they are absorbed into development researches having strong commercial viability since professors use them as cheap research labors, it is warned that they can be trapped failures, not performing academically excellent researches (Lam 2007).

Existing studies on the relationship between the size of research groups and productivity have produced complex findings. Research productivity in small groups is typically reported to increase as the size increases; however, after groups reach a certain size, productivity generally falls: the optimal research group size is generally estimated be five to nine researchers (Johnston 1994). However, the size of the research group is not the only factor. For example, according to Davis and Royle (1996), despite the fact that most Australian research is produced by large universities, the quality of research was higher in small, newly established universities.

Other factors such as gender, age, funding, and scientific equipment also play important roles in research productivity. Gender has long been known to be associated with significant differences in research productivity, with gender-related differences in research productivity assumed to be the result of sociological factors, especially females' tendency towards occupying relatively lower positions in power hierarchies (Zuckerman et al. 1991; Sonnert and Holton 1996; Reskin 1979). Older age has also been found to correspond with a decrease in research productivity (Stephan 1996; Stephan and Levin 1992); this is likely due to the fact that the profits following personal knowledge-based investment decline with advanced age. Researcher career and age tend to have an inverted U-shaped relationship, which reaches its peak at the early stageof the career (Baser and Pema 2004; Oster and Hamermesh 1998).

Material resources, such as the amount of funding, are critical for research productivity Government support of scientific research and development has been taken for granted because it is a public good (Arrow 1962). However, the question of whether governmental funding is crowding out private funding is a critical concern (David et al. 2000), and it is important to identify to how to maximize the effectiveness of government research funding (Jacob and Lefgren 2007). The possession of scientific instrument s(e.g., microscopes, telescopes, X-ray analyzers, centrifuges, particle accelerators, and spectroscopes)has also been argued to be an important factor of scientific advancement, as what instruments a research group has access to affects what analyses and measurements they can make (Rosenberg 1982, p. 234).

Data & methodology

Data

The data used in this research were obtained from a study entitled "A study on academic research and development activities in Korea," an annual study conducted by the NRF on four-year universities in 2009. The number of graduate students managed by each researcher who had projects supported by the NRF was also measured and piled in a data system call as E-R&D. In Korea, research funds for university researchers are mostly provided by the Ministry of Education and Science, and almost all research costs are covered by the NRF. The NRF collects and manages data on all professor–researchers who receive funds, including the number of graduate students involved in research. Although establishing long-term panel data on researchers and performing empirical analyses would be more appropriate, this type of analysis was not done due to the very short time span covered by the data, as well as the different ways of collecting data each year.

Previous studies have argued for the existence of selection bias, meaning that the only researchers included in studies on productivity are those who are already productive above a certain level. Results may be overestimated, as samples included in empirical analyses mostly targeted researchers who benefitted from research funds (Arora and Gambardella 1998). Also, even though government research funding has been shown to enhance productivity (e.g., Lerner 1999), these studies were criticized for their serious selection bias (Klette et al. 2000). In contrast, the data used in this research are believed to be free of this selection bias problem because this dataset includes all professor–researchers with full-time lecturer positions at Korean universities. Data are categorized by the respective researcher's project, unique data that only the NRF possesses. Researchers are categorized according to field of study into humanities, social sciences, natural sciences, and engineering as shown in Table 1.

Methodology

The goal of this study is to analyze differences in researchers' productivity in relation to the number of graduate students they manage. The independent variable, *graduate students*, refers to the number of graduate students that each respective researcher hires; this figure was obtained in 2009 by the number of graduate students involved in the projects that NRF supported from 2005 to 2007. The dependent variable, research productivity, was defined as *research career*. This was calculated by dividing the number of papers produced by each researcher in 2008 into Korea Citation Index (KCI) and Science Citation Index (SCI) scores measuring domestic and foreign

Table 1 Number of academics by disciplines

Disciplines	Frequency	%
Humanities	8,955	23.47
Social sciences	12,807	33.57
Natural sciences	5,513	14.45
Engineering	10,874	28.5
Total	38,149	100

Table 2 Dependent, independent variables, and descriptive statistics

Category	Index	Definition and measurement	Average (standard deviation)
Dependent Variable	Pub_1	KCI-Level Research Outcomes	0.4238119(0.4941678)
	Pub_2	SCI-Level Research Outcomes	0.1497811(0.3568614)
Independent Variable	Graduate Students	Number of Graduate Students	
Control Variable	Gender	1 = Dummy of Females	
	Grant_gov	Natural Logarithm of Government's grants to research cost	
	Grant_pri	Natural Logarithm of the size of private grants to research cost	
	Grant_inner	Natural Logarithm of the size of inner grants to research cost	
	Age	Age	
	Age^2	Age Squared	
	Nation	Dummy of Institution Trained	
	NU	Dummy of National/Public Universities	
	Region	Regional Dummy Variable	
	Cur	Dummy of Classification of disciplines	

publication, respectively. For co-authored papers, individual paper outcomes were divided by the total number of authors (n +2).

Control variables were gender, amount of funding (government-funded, enterprise-funded, or university-funded), age, institution trained (domestic or foreign) where researchers obtained their degree, region (capital or non-capital), and researchers' disciplines. *Age* was calculated by adding squared terms, in accordance with previous findings that researchers' careers have a quadratic function form characterized by negative values associated with higher age (Baser and Pema 2004; Oster and Hamermesh 1998; Kenny and Studley 1996; Kyvik 1990; Diamond 1980).

Source of research funding was classified as government-funded, enterprise-funded, or university-funded (David et al. 2000; Jacob and Lefgren 2007; Jaffe 2002). The institution trained (domestic or foreign) where graduate students acquired their degree was coded as "1" for domestic graduates (i.e., within Korea) and "0" for foreign graduates (i.e., outside of Korea). Geographical regions were also divided into two categories (i.e. capital and non-capital) as a dummy variable; researchers' disciplines were controlled as a dummy variable as well. Also, as differences in research outcomes have been found to correspond with disciplines of researchers, we classified each field based on NRF classifications (see Table 2).

Results

t-test

All researchers included in this study were classified into the four disciplines specified by the NRF, covering the fields of humanities, social sciences, natural sciences and engineering. Table 3 compares the number of graduate students for each discipline. According to Table 3, university professors in engineering have more students than any other field; within this field, 10,874 professors engage in research,

Table 3 Number of graduate students by disciplines

Disciplines	Size (No. of Professors)	Average	S.D.	Variation coefficient
Humanities	8,955	1.057	0.050	4.730
Social sciences	12,807	1.920	0.054	2.813
Natural sciences	5,513	5.415	0.147	2.715
Engineering	10,874	7.346	0.122	1.661

and they manage 7.3 graduate students each, on average. The average number of graduate students per researcher for the other disciplines is 5.4 in natural sciences, 1.9 in social sciences, and 1.1 in humanities. This indicates that researchers in the natural sciences and engineering employ more students than those in the humanities and social sciences. As confirmed in the variation coefficient measured to compare differences in deviation among the disciplines (see Table 3), while professors in engineering had a relatively uniform distribution of graduate students, those in humanities was verified to deviate severely with regard to the procurement of graduate students among researchers.

Table 4 indicates the number of graduate students according to gender (i.e. male or female), age (i.e. junior or senior), and region (capital or non-capital area). First, when comparing the number of graduate students per researcher by gender for each discipline, professors in all disciplines except social sciences were found to have statistically significantly more male graduate students than female students, although findings

Table 4 T-test of size of graduate students by factors

	Gender			Age			Region		
Disp	Group	Obs	Avg.	Group	Obs	Avg.	Group	Obs	Avg.
H	Male	6,780	1.186(0.063)	Senior	5,409	1.211(0.071))	Non-capital	4,722	0.881(0.062)
	Female	2,175	0.654(0.069)	Junior	3,546	0.822(0.066))	capital Area	4,233	1.253(0.082)
	combined	8,955	1.057(0.050)	combined	8,955	1.057(0.050)	combined	8,955	1.057(0.050)
	diff		0.532(0.118)	diff		0.389(0.103)	diff		−0.372(0.101)
	t-value	4.5275**		t-value	3.7735*		t-value	−3.6778**	
SS	Male	10,683	1.937(0.059)	Senior	7,649	2.015(0.075)	Non-capital	7,108	1.665(0.067)
	Female	2,124	1.834(0.131)	Junior	5,158	1.779(0.075)	capital Area	5,699	2.238(0.087)
	combined	12,807	1.92(0.054)	combined	12,807	1.920(0.054)	combined	12,807	1.92(0.054)
	diff		0.102(0.145)	diff		0.236(0.110)	diff		−0.573(0.108)
	t-value	0.7069		t-value	2.1474**		t-value	−5.2854**	
NS	Male	4,385	5.752(0.170)	Senior	4,027	4.910(0.166)	Non-capital	3,406	5.257(0.182)
	Female	1,128	4.105(0.278)	Junior	1,486	6.785(0.304)	capital Area	2,107	5.671(0.248)
	combined	5,513	5.415(0.147)	combined	5,513	5.415(0.147)	combined	5,513	5.415(0.147)
	diff		1.648(0.363)	diff		−1.875(0.330)	diff		−0.414(0.302)
	t-value	4.5351**		t-value	−5.6817**		t-value	−1.3709	
E	Male	10,466	7.419(0.125)	Senior	7,736	7.122(0.144)	Non-capital	7,083	7.328(0.148)
	Female	408	5.478(0.526)	Junior	3,138	7.897(0.225)	capital Area	3,791	7.38(0.214)
	combined	10,874	7.346(0.122)	combined	10,874	7.346(0.122)	combined	10,874	7.346(0.122)
	diff		1.941(0.640)	diff		−0.775(0.268)	diff		−0.053(0.255)
	t-value	3.0336**		t-value	−2.8886**		t-value	−0.2070	

H humanities, *SS* social science, *NS* natural science, *E* engineering
* $p < 0.05$, ** $p < 0.01$, the value of () is standard errors

differed by field of study. The disciplines of natural science and engineering had particularly notable findings, with an average of 1.5–2.0 more students per male professor than per female professor.

Second, we found significant differences in the total number of graduate students employed by senior and junior researchers across all four disciplines. Senior professors were also found to have more graduate students than junior professors in humanities and social sciences, but in contrast junior professors in natural science and engineering have more students than senior professors.

Finally, we found a statistically significant difference in the number of graduate students employed in capital versus non-capital regions for both the humanities and social sciences, with professors in both disciplines employing larger numbers of graduate students per researcher in capital areas than in non-capital areas. In contrast, no such regional difference was identified for the natural sciences or engineering. As the number of graduate students is generally proportional to the size of research funds, this difference might have arisen from funding differences between capital and non-capital areas (Kwon 2010).

Regression analysis

Table 5 presents the findings for the control variables. First, coefficients of variables for research funding (government-funded, enterprise-funded, or university-funded) were found to be significantly positive for most of disciplines. This result is similar to previous studies on the influences of research funding on research productivity (Jacob and Lefgren 2007). Second, coefficients for the variable of *gender* were significantly negative, except in the field of engineering. This means that, holding all other variables equal, male researchers' KCI research scores were lower than those of female researchers. Although SCI scores will be discussed later in greater detail, we will note here that male researchers' SCI scores were found to be significantly higher than female researchers' SCI scores. Possibly, this finding is due to the fact that, more than their female counterparts, male researchers in Korea strive to stack their research output to maximize SCI scores, while making less effort towards their KCI scores. Third, the coefficients of *age variable* and *age2*, which we employed as control variables, were statistically significant in all areas. The coefficient for age2 was significantly negative; this confirms the results of previous studies that found research output to have a quadratic function form, with negative coefficients associated with age Baser and Pema (2004); Oster and Hamermesh 1998; Kenny and Studley 1996; Kyvik 1990; Diamond 1980). Fourth, the nation variable (foreign vs. domestic) of degree completion employed as control variable had significantly positive values for all disciplines except the social sciences; this indicates that, other factors being equal, professors trained in domestic institutions have higher KCI scores than those trained in foreign institutions. Fifth, the research outcomes of professors from national or public universities tended to be significantly bigger than the research outcomes of researchers from private universities.

The independent variable of *graduate students* was shown to have significantly positive coefficients for all disciplines except the humanities, meaning that more graduate

Table 5 Estimation of productivity as measured by the number of KCI papers

Variable	Total	Humanities	Social sciences	Natural sciences	Engineering
Number of Graduate Students	0.002** (0.0001)	0.002 (0.001)	0.004** (0.001)	0.002** (0.001)	0.003** (0.0001)
Incen	0.008** (0.001)	0.018** (0.002)	0.013** (0.001)	0.001 (0.001)	0.007** (0.001)
Inpri	0.007** (0.001)	0.013** (0.004)	0.009** (0.002)	0.015** (0.002)	0.005** (0.001)
Ininner	0.026** (0.001)	0.036** (0.001)	0.027** (0.001)	0.016** (0.001)	0.019** (0.001)
Gender(1 = Male)	−0.043** (0.007)	−0.036** (0.011)	−0.039** (0.012)	−0.079** (0.019)	−0.015 (0.025)
Age	0.081** (0.003)	0.088** (0.005)	0.079** (0.005)	0.066** (0.008)	0.066** (0.006)
Age^2	−0.001** 0.000	−0.001** 0.000	−0.001** 0.000	−0.001** (0.0001)	−0.001** (0.0001)
Nation(1 = Domestic Doctorates)	0.025** (0.005)	0.008** (0.011)	0.011 (0.009)	0.063** (0.013)	0.030** (0.010)
NU(1 = National/Public Universities)	0.075** (0.006)	0.075** (0.012)	0.071** (0.010)	0.059** (0.014)	0.070** (0.010)
Region (1 = capital Area)	0.001 (0.005)	0.005 (0.010)	0.030** (0.009)	−0.045** (0.014)	−0.017** (0.011)
Intercept	−1.500** (0.072)	−1.744** (0.119)	−1.315** (0.133)	−1.263** (0.205)	−1.213** (0.153)

* $p < 0.05$
** $p < 0.01$

students results in relatively higher KCI research output scores. Based on this finding, policies should be put into place to help researchers with limited resources to obtain graduate students.

In comparison to Table 5, which uses KCI scores, Table 6 analyzes results using SCI scores as the dependent variable. Although the coefficient values of research funding (government-funded, enterprise-funded, or university-funded) differed according to disciplines, coefficients were significantly positive for most fields of study. This confirms the findings of previous studies regarding the impact of funding on research productivity, with more funds contributing to increased SCI research output scores. The coefficient of*age* was shown to be significantly positive except for in the humanities, assuming that all other variables are identical, male researchers had overall higher SCI research output scores than their female counterparts. As discussed relative to Table 5, findings presented in Table 6 confirm that male researchers in Korea make more efforts to increase their SCI scores, while female researchers instead strive to increase their KCI scores. This may be due to the fact that female professors are hard to find overseas journals as most of them belong to humanity department (NRF 2009).

The coefficient for the control variables of age was significantly positive in both the natural sciences and engineering. Also, in both areas, the coefficient value of age2 was significantly negative. Further, the control variable of professors' foreign or domestic degree earned had significantly negative values in all areas, meaning that researchers graduating from universities outside of Korea had significantly higher SCI research output scores than researchers who got their degrees from domestic universities. Additionally, researchers in national or public universities tended to have higher research outputs than those in private universities, except for in the field of social science.

For the independent variable of *graduate students* we found significantly positive coefficients in all fields. This indicates that managing more graduate students is associated with higher SCI research output scores. Therefore, policies of supporting graduate students need to be implemented for researchers managing small number of graduate students because of the less privileged research environment.

Conclusion

The key findings of the present study are, first, that male researchers managed more graduate students than female researchers. We assume that this is due to the relatively higher proportion of research funding that is given to male researchers, as well as the social tendency to recognize the research output of males more than that of females. Second, we found that senior researchers had more graduate students, than junior researchers only in humanities and social sciences. Third, researchers from capital areas had more support for their research, and managed more graduate students, than researchers from non-capital areas. Last, the number of graduate students managed was found to be associated with significant differences in researchers' output, as measured by both KCI and SCI scores.

Industrialized countries such as Korea aim to promote policies that support talented researchers and maximize their productivity, improving national standing in the academic community and enlarging both the national and global knowledge level. As overall research funding rises in accordance with the increasing national emphasis on research development, the effective and efficient management of funds is critical. Many

Table 6 Estimation of productivity as measured by the number of SCI papers

Variable	Total	Humanities	Social sciences	Natural sciences	Engineering
Number of graduate students	0.003** (0.0001)	0.0001* (0.0001)	0.001* (0.0001)	0.005** (0.001)	0.002** (0.0001)
Incen	0.012** (0.0001)	0.002** (0.0001)	0.004** (0.001)	0.020 (0.001)	0.015** (0.001)
Inpri	0.007** (0.001)	0.001 (0.001)	0.003** (0.001)	0.004** (0.002)	0.009** (0.001)
Ininner	0.005** (0.0001)	0.001* (0.0001)	0.002** (0.0001)	0.013** (0.001)	0.009** (0.001)
Gender (1 = Male)	0.025** (0.005)	−0.002 (0.002)	0.017** (0.005)	0.080** (0.018)	0.080** (0.020)
Age	0.009** (0.002)	0.000 (0.001)	0.004 (0.002)	0.002** (0.008)	0.028** (0.005)
Age^2	−0.0001** (0.00001)	−0.0001 (0.0001)	−0.0001 (0.0001)	−0.0001** (0.00001)	−0.0001** (0.00001)
Nation(1 = Domestic Doctorates)	−0.046** (0.003)	−0.005* (0.002)	−0.026** (0.004)	−0.087** (0.012)	−0.090** (0.008)
NU(1 = National/Public Universities)	0.027** (0.004)	0.006** (0.002)	0.007 (0.004)	0.061** (0.013)	0.051** (0.009)
Region (1 = capital Area)	0.040** (0.003)	0.003 (0.002)	0.033** (0.004)	0.063** (0.013)	0.072** (0.009)
Intercept	0.382** (0.047)	0.005 (0.023)	0.172** (0.058)	0.458** (0.194)	0.921** (0.126)

The value of () is Std. Err. ** p <0.01, * p <0.05

industrialized countries are especially interesting in promoting research support for underrepresented groups;according to the findings of the present study, these groups include female researchers, junior professors, and researchers from non-capital areas. Establishing and promoting policies privileging these underrepresented groups would enhance national scientific competitiveness and overall research output.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
All authors read and approved the final manuscript.

Author details
[1]Hanbat National University, Daejeon, South Korea. [2]National Research Foundation of Korea, Daejeon, South Korea. [3]Korea Institute of Ocean Science & Technology, Gyeonggi-do, South Korea.

Received: 3 September 2015 Accepted: 8 December 2015
Published online: 21 December 2015

References

Arora A, Gambardella A. The impact of NSF support for basic research in economics, Working paper, Carnegie-Mellon University. 1998.

Arrow K. Economic Welfare and the Allocation of Resources for Invention. In: NBER Chapters, The Rate and Direction of Inventive Activity: Economic and Social Factors. Cambridge: Princeton Univerisity Press; 1962. p. 609–26.

Baser O, Pema E. Publications over the academic life cycle: evidence for academic economists. Econ Bull. 2004;1:1–8.

Brew A. Research and teaching. UK: Palgrave Macmillian; 2006.

David PA, Hall BA, Toolr AA. Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. Res Policy. 2000;29:497–529.

Davis G, Royle P. A comparison of Australian university output using journal impact factors. Scientometrics. 1996;35(1):5–58.

Diamond AM. Age and the acceptance of cliometrics. J Econ Hist. 1980;40(4):838–41.

Hess DJ. Science studies. New York: New York University Press; 1997.

Jacob B, Lefgren L. The impact of research grant funding on scientific productivity, Working Paper 13519, NBER working paper series. 2007.

Jaffe AB. Building programme evaluation into the design of public research-support programmes. Oxf Rev Econ Policy. 2002;18:22–34.

Johnston R. Effects of resource concentration on research performance. High Educ. 1994;28(1):25–37.

Kenny L, Studley R. Economists' salaries and lifetime productivity. South Econ J. 1996;65:382–93.

Klette T, Moen J, Griliches Z. Do subsidies to commercial R&D reduce market failures? Microeconomic evaluation studies. Res Policy. 2000;29:471–95.

Kwon K-S. Universities' academic research and knowledge-transfer activities in a catch-up country: the case of Korea. DPhil Thesis. SPRU, Brighton: University of Sussex; 2010. http://sro.sussex.ac.uk/2337/.

Kwon K-S. Are scientific capacities and industrial funding critical for Universities' knowledge-transfer activities in a catch-up Country? The case of South Korea. J Contemp Eastern Asia. 2011;10(1):15–23.

Kyvik S. Age and scientific productivity: difference between fields of learning. High Educ. 1990;19:37–55.

Lam A. Knowledge networks and careers: Academic Scientists in Industry-University links. J Manag Stud. 2007;44(6):993–1016.

Lerner J. The government as venture capitalist: the long-run impact of the SIBR program. J Bus. 1999;72(3):285–318.

NRF. A Study on Academic Research and Development Activities in Korea. Survey Report. South Korea: National Research Foundation of Korea; 2009.

Oster SM, Hamermesh DS. Aging and productivity among economists. Rev Econ Stat. 1998;80:154–6.

Patra SK, Krishna VV. Globalization of R&D and open innovation: linkages of foreign R&D centers in India. Journal of Open Innovation: Technology, Market, and Complexity. 2015;1(7). doi:10.1186/s40852-015-0008-6.

Reskin BF. Academic sponsorship and scientists' careers. Sociol Educ. 1979;52(3):129–46.

Rosenberg N. Inside the black box: technology and economics. Cambridge: Cambridge University Press; 1982.

Ryu H, Pae J. An analysis of the determinants of research productivity among professors of science and engineering. J Technol Innov. 1997;5(1):4–66 [in Korean].

Salter A, D'Este P, Pavitt K, Scott A, Martin B, Geuna A, Nightingale P, Patel P. Talent, Not Technology: Publicly Funded Research and Innovation in the UK.a report commissioned by the CVCP and HEFCE, SPRU. UK: University of Sussex; 2000.

Song H. A study on research productivity of college professors in Korea, Master Thesis. South Korea: YonseiUniverisity; 2001 [in Korean].

Sonnert G, Holton G. Career patterns of women and men in the sciences. Am Sci. 1996;84(1):63–71.

Stephan PE. The economics of science. J Econ Lit. 1996;36:1199–235.

Stephan P, Levin S. Striking the mother lode in science. London: Oxford University Press; 1992.

Von Tunzelmann N, Ranga M, Martin B, Geuna A. The effect of size on research performance: a SPRU review. Report prepared for the Office of Science and Technology, Department of Trade and Industry, SPRU. UK: University of Sussex; 2003.

Zuckerman H, COLE J, Bruer J, editors. The outer circle: woman in the scientific community. New York: W.W.Norton; 1991.