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Determinants of research productivity in Korean Universities: the role of research funding

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Abstract

University research is a vital source of innovation, and government funds are often used to support innovative research programs. As such, universities are pressured to demonstrate returns on investments through tangible research outcomes. This study analyzed how university resources affect research productivity, using data from 95 4-year universities in Korea from 2009 to 2017. Explanatory variables were remuneration, performance-based payments, and expenditures on research, experiments, machines, and books. Research productivity indices were the numbers of Korea Citation Index (KCI) and Science Citation Index (SCI) publications, authored books, patents attained, and licensing revenue. Considering that research productivity measures are related, this study used a seemingly unrelated regression (SUR) model. The SUR model analysis showed that SCI, patents, and licensing revenue were correlated and resources differentially affected research productivity. Full-time faculty remuneration, performance-based payments, and research expenditure were significant variables in determining SCI, patents, and licensing revenue. Results of quadratic form regression showed that research productivity increased when full-time faculty remuneration increased, but these gains were limited by the law of marginal diminishing returns. However, the performance-based payment variable showed opposite results, reflecting the law of marginal increasing returns. Combined results will help universities set their strategic direction, efficiently allocate their resources, and promote understanding about university functions.

Keywords Research productivity · R&D resources · Panel data analysis · Korean universities

JEL Classification I22 · I23 · O31 · O32

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1 Introduction

Universities are organizations that produce various outputs such as education, research, and service (Johnes 2016). During the 1950s and 1960s, policymakers and scientific communities witnessed the expansion of scientific information and recognized the importance of university research (Leydesdorff and Wagner 2009). Since the late 1970s, there has been an emphasis on university-industry collaborations to bring the results of academic research to commercial markets (Muscio et al. 2013).

Universities play an essential role in economic and social development through the creation and dispersion of knowledge (Florida and Cohen 1999). As the knowledge society develops, there is increasing awareness regarding the importance of university research (Muscio et al. 2013). As universities' research is recognized as a vital source of innovation and economic policy (Phillimore 1988), considerable attention has been focused on research productivity (Beaudry and Allaoui 2012; Schuelke-Leech 2013). Accordingly, growing pressure has been put on universities to promote research productivity (Muscio et al. 2013). In addition, as a large proportion of government funds flows to universities, assessing the effects of this financial investment is imperative (Belfield and Fielding 1999). Additionally, in the era of neoliberalism, universities have come to emphasize market governance and management (Reed 2002), and research productivity serves as a key factor in university management (Sandström and Van den Besselaar 2018). In this situation, it is necessary to identify factors that affect research productivity at universities (Hicks 2012).

However, it is not easy to identify the mechanisms of research productivity. There is no single accepted definition of "research productivity" (Oya 2017), and there is little agreement about what constitutes or determines productive research outcomes (Phillimore 1988). Because universities are multi-product organizations with complex production processes (Johnes 2016), it is not easy to clarify the determinants of research productivity. For example, Dundar and Lewis (1998) describe the determinants of research productivity as individual and institutional (departmental) attributes and suggest that studies should focus on institutional attributes to enhance research productivity. However, Gonzalez-Brambila and Veloso (2007) focus on individual characteristics to analyze the determinants of research productivity.

There is extensive evidence about the effects of government funding on research productivity (Salter and Martin 2001). In addition, there have been various forms of analysis on the factors affecting research productivity at the institutional level (Dundar and Lewis 1998; Golden and Cartensen 1992a; Rushton and Meltzer 1981). However, the effect of funds on research productivity has been evaluated on the aggregate. Even though university resources serve as key input factors that determine the quality and performance of universities, previous studies provide little insight into its specific determinants. Resources may be internal or external (Schuelke-Leech 2013) and may be composed of diverse items such as labor and research costs, incentives, etc. Different resources may generate different outcomes. The range of resources and the returns on these investments must be considered to discern the inefficiencies in resource distribution and misallocations of resources, as well as to provide criteria for prioritizing resource expenditures. We have scant empirical evidence whether and to what extent resources affect university research productivity. Furthermore, these studies failed to sufficiently consider the characteristics of universities as organizations as well as financial investments. For example, a university is an organization that produces multiple complex outputs, yet studies consider only a few of these. Moreover, universities are labor-intensive organizations (Winston 1999) and thus there may be the law of diminishing returns on some resources, but this is not considered.

This study analyzes the determinants of research productivity in Korean universities, considering these problems. The Korean government is carrying out various policy projects to promote research functions at universities (Kim and Na 2005), and research productivity is used as a key indicator for evaluating universities. Korean universities are examining their current management styles and seeking more efficient ways to utilize their resources for gaining competitive advantages. As a result of these efforts, Korean universities have experienced an enormous increase in research productivity (Leydesdorff and Wagner 2009), yet this productivity is not equivalent to world class research universities (Shin 2009).

This study investigates the determinants of research productivity in Korean universities. The guiding research questions of this analysis are: What are the empirical findings regarding the relationship between university resources and university research performances in Korean Universities? What are the resource determinants of research productivity in Korean universities? Analysis of the effects of resources on research productivity will help universities set their strategic direction, efficiently utilize their resources, promote understanding about administration, and enable in-depth understanding about university functions. Thus, this study will provide useful implications about university research and promote university competitiveness.

The rest of this study is organized as follows: Section 2 reviews the prior literature about determinants of research productivity. Section 3 discusses the theoretical framework, and the subsequent section describes the data. The fifth section describes the estimation method, while the sixth section presents the result and identifies the main policy implications. The final section provides conclusions.

2 Research on university research performance

Previous research can be divided into two strands. The first is interested in the effects of government funding or resources on research productivity (Auranen and Nieminen 2010; Leydesdorff and Wagner 2009; Sandström and Van den Besselaar 2018; Shin 2009). Researchers call on policy makers to focus on the expansion of government resources and assert the need to analyze the effect of resources on research productivity at the macro level (Jacob and Lefgren 2011). For example, Auranen and Nieminen (2010) analyzed the scientific publication mechanisms of eight countries. They investigated how funding environments of university research differed across countries and whether more competition and incentives boosted university research productivity. Auranen and Nieminen (2010) framed countries' funding systems according to their share of external funding and orientation of core funding devoted to research. This analysis found no connection between financial incentives and the efficiency of university systems. Sandström and Van den Besselaar (2018) explored determinants of national research system performance. They measured the efficiency of 18 countries using the rate of change in funding (input variable) and highly cited papers (output variable). Through this analysis, Sandström and Van den Besselaar (2018) showed that input changes to the science system largely determined changes in output. There was a small but negative correlation between efficiency and the level of competitive project funding. Finally, Shin (2009) analyzed the effect of South Korea's Brain

21 (BK21) project. BK21 is a government research program granted to enhance research productivity. Specifically, BK21 investigates whether special funds increase universities' research productivity. Using interrupted time-series design methodology, Shin (2009) demonstrated that BK21 was successful in increasing journal publications in the Science Citation Index (SCI) and had a positive effect on the system and entire culture of Korean universities.

The second strand of previous investigations on the determinants of research productivity is focused at the university level. Factors affecting research productivity at the university level can be divided into two attributes: individual and institutional. Individual attributes include sex, age, discipline, etc. (Carayol and Matt 2006; Gonzalez-Brambila and Veloso 2007). For example, Gonzalez-Brambila and Veloso (2007) explored the determinants of output and impact for Mexican researchers. They found a quadratic relationship between age and the number of published papers. Even though individual-level studies provide useful information about research productivity, for public policy to enhance research productivity, departmental and institutional attributes need to be examined (Dundar and Lewis 1998).

Institutional attributes relate to human resources (Baird 1991; Dundar and Lewis 1998; Jordan et al. 1989; Rushton and Meltzer 1981), reputation and mission of the school (Jordan et al. 1989), facilities (Porter and Toutkoushian 2006), and resources. Studies on resource and research productivity (Abbott and Doucouliagos 2004; Dundar and Lewis 1998; Beaudry and Allaoui 2012; Heisey and Adelman 2011) yield different results based on their focus and methods. For example, Abbott and Doucouliagos (2004) explored the relation between research outcomes and research income, academic and non-academic labor, and characteristics of Australian universities. Using pooled least square regression and generalized least square regression methods, study results indicated that research income, academic staff, and postgraduates determine research output. Dundar and Lewis (1998) investigated the determinants of research productivity at the departmental level, measuring research productivity as the ratio of total publications to number of program faculty. Using polynomial regression, Dundar and Lewis (1998) found that the effect of program size diminished as size increased. Beaudry and Allaoui (2012) investigated the impact of public grants, private contracts, and collaboration on the scientific production of Canadian nanotechnology academics. Based on the assumption that academics who obtain more public funding generate more articles, they analyzed the relation between the number of articles and grants, contracts, patents, and corroborative network. Using a negative binomial regression model, Beaudry and Allaoui's (2012) results showed that public research funds led to more scientific articles. Relating to licensing revenue, Heisey and Adelman (2011) investigated determinants of university revenue focusing on research expenditures and technology transfer activity. Using a dynamic panel model, they found short term impacts of research expenditures on licensing revenues. Their results also showed that one-year lagged licensing revenue was a strong predictor of current licensing revenue (Table 1).

In summary, many studies examined research productivity in universities, but relatively few analyzed the effects of financial investment on research. Previous studies also failed to consider the following three issues. First, there is an issue of resource scope. While previous studies analyzed factors affecting research productivity, resources were analyzed only in terms of a limited concept. Research resources are complex and composite (Schuelke-Leech 2013). Government resources flowing to universities are divided into specific cost categories such as labor, purchase, research management costs, and so on, a situation not considered in previous studies. Rather, studies only analyzed whether resources influenced research productivity (Auranen and Nieminen 2010; Beaudry and Allaoui 2012;

Table 1 Summary of literature review

Researcher	Independent variable	Dependent variable	Methodology	Results	Analysis level
Auranen and Nieminen (2010)	8 countries Total R&D expenditure Mechanism of government fund Funding source of research funding	Scientific publication	Ratio analysis (funding per publication ratio)	No mechanism between funding incentives and research activity	National (Macro level)
Sandström and Van den Besselaar (2018)	18 countries The rate of change in funding Differences in funding systems Level of competition Level of university autonomy Level of academic freedom	National science system efficiency (the increase in highly cited pater) per percentage increase in funding	Regression	Small but negative correlation between efficiency and the level of competitive project funding	National (Macro level)
Shin (2009)	Government funding	Journal publications in the Science Citation Index (SCI)	Interrupted time-series design	Positive relation	National (Macro level)
Gonzalez-Brambila and Veloso (2007)	Time variant variables: age, age square, level, stock of past publications, budget, total no. of researchers in the same area, total no. of publications in the same area Time invariant variables: area of knowledge, gender, institution, country of PhD, cohort	Research out put the no. of published papers Research impact: no. of citations	Negative binomial fixed effects model	Quadratic relationship between age and the no. of publish paper Reputation matter for the no. of citations	Individual (Micro level)

Table 1 (continued)

Researcher	Independent variable	Dependent variable	Methodology	Results	Analysis level
Abbott & Doucouliagos (2004)	No. of academic and non-academic staff Research income Total no. of full-time student No. of full-time equivalent postgraduate enrolments Medical school No. of campuses Time	Research quantum (composite Index, based upon the research output of universities Publication index (conference paper, book chapter, books, and journal article)	Pooled least square regression Generalized least Square regression	Research outputs are associated positively With research income, academic staff, post-graduates	Department (Micro level)
Beaudry and Allaoui (2012)	Grant (the average amount of funding over the past 3 years) Contract (average amount of contract over the past 3 years) Patent (no. of patent application of the past 3 years) 3-year network centrality and cliquishness Nanotechnology career age Age, age square University dummy	The no. of articles published in a given year	Negative binomial regression model	Positive effect of grant No effect in contract Inverted-u shaped curve in patent Positive effect of collaborative network	University (Meso level)
Heisey and Adelman (2011)	Research expenditure Characteristic of university (with medical school, land grant university) University technology transfer	Licensing revenues	Panel dynamic model	Expenditure show short term impact on licensing revenue	University (Meso level)

Shin 2009). This issue applies to departmental- or institutional-level studies that use limited resource variables. For example, Golden and Cartensen (1992a) stressed the effects of financial investments by comparing public and private universities, arguing that private universities prioritize research productivity by providing greater salaries and incentives. However, their study considered only factors such as faculty salaries and incentives. Although faculty remuneration is an important factor affecting research productivity in universities, there are also other factors such as expenditures on experiments or research, and students. Despite the diverse financial factors and importance of each variable on research productivity, these factors are omitted in the analysis and thus may raise issues of bias or inefficiency in the estimated values.

Second, analysis on research productivity in universities has not been systematic. Despite the diverse and complicated aspects of research productivity (Phillimore 1988), only a few indicators have been used for analyses. For example, Dundar and Lewis (1998) used the number of journal publications as the dependent variable in their analysis. Rushton and Meltzer (1981) analyzed the number of citations in publications by 169 universities in Canada, the U.S., and U.K., using variables such as the number of books and journals in the library, and university finances. Research productivity in universities appears in various forms (Phillimore 1988), which may be correlated. However, in previous studies there are few dependent variables, which fail to use information on potential correlations among them.

Third, there is an issue of level of analysis. Previous studies analyzed the effect at the level of government resources or at the level of individuals and departments. Government funding sources are emphasized at the national level and for international comparisons (Auranen and Nieminen 2010; Sandström and Van den Besselaar 2018). Even though some researchers analyze the university level, they focus on the department level, such as comparing the college of social sciences or engineering or analyzing the research productivity of a specific department. For example, Crewe (1988) studied research productivity of the politics department in U.K. universities and discovered great variation among departments. Johnes (1988) analyzed the research output of economic departments in British universities and indicated that most of the variations between research outputs of departments can be explained by the differences in inputs. In light of these arguments, this study aims to analyze the determinants of research productivity focused at the university level.

3 Factors influencing university research performance

A university is a type of business or organization that produces and sells educational services to customers (Winston 1999). Universities are multi-purpose professional organizations with diverse functions and complicated production mechanisms. In other words, universities have the characteristics of joint production as they simultaneously produce diverse functions such as education, research, and service. There are difficulties in analyzing how these outputs are affected by financial investment.

Despite these challenging characteristics, there are various theories used to analyze university productivity related to financial investments, such as the educational production function (Hanushek 1986), knowledge production function (Griliches 1990), Schumpeter model (Philippe 2004), and influential factors model. Educational production function regards educational activities as a production process and expresses the relationship of using minimum input to produce maximum educational output in the form of a mathematical function. If one input is relatively more predictive in the production of an output, this input will be highly used. In other words, it expresses the relationship between input and output in a functional formula (Pritchett and Filmer 1999). This approach is to determine factors affecting academic achievement and can be used in analyzing financial investments and research productivity as well. Similar to the educational production function, we can consider the knowledge production function in research (Griliches 1990). Knowledge production function provides the background for understanding the link between innovative inputs and outputs. This theoretical framework allows us to understand the empirical assessment between inputs and outputs (Conte and Vivarelli 2005).

The Schumpeter model is used to explain the research and development (R&D) mechanism in private research organizations (Philippe, 2004; Schumpeter 1942). Its premise is that many risks and uncertainties must be overcome to produce R&D outcomes. Moreover, a great deal of finances must be invested in order to produce research outcomes in organizations, which indicate investment in R&D workforce, investment in materials, and rewards for positive R&D outcomes (Cohen and Klepper 1996). Although the Schumpeter theory is used to explain the R&D mechanism in private companies, it can also be used to determine factors affecting research productivity in universities (Abbott and Doucouliagos 2004).

While these theories explain the importance of resources in research performance, scant information is available about the relationship between resources and research performance. Universities include a collection of resources such as faculty, financial resources, physical resources, and so on, and they produce varying levels of research performance. Some resources held by universities may play a key role in determining their research performance, and universities that focus on their capabilities through efficient allocation of resources generate different results in their performance (Landry, Rherrad, and Amara 2005). Other resources may play a minor role on productivity or may negatively influence research performance (Schuelke-Leech 2013). In this context, an analysis about the relationship between university resources and university performance, and the determinants of research performance, is important.

A university is a labor-intensive organization that requires a large amount of faculty labor to produce research. Because faculty salaries make up the largest part of university expenditures, they are central to the productivity of the university. It is widely accepted in the literature that academics respond to peer recognition and the advancement of science, but pecuniary resources strongly predict research performance (Lach and Schankerman 2008).

In this case, capital can be considered the application or investment of resources to create research performance (Lin 2001). Capital can be used to purchase materials and experiment. The combination and utilization of capital resources within a university is essential for research performance.

Physical resources are all the structures found in a university system along with the raw materials that are used to achieve an objective or goal of the university. Physical resources include laboratories, libraries, and a host of other types of physical infrastructure. Physical resources are needed for the day-to-day running of the organization (Barney 1991). As they relate to research, physical resources provide researchers with room and tools to conduct research, and they play a pivotal role in the actualization of research (Allison and Long 1990). In this vein, this study established the follow hypothesis and sub-hypotheses.

Hypothesis 1 Financial resources will have positive effects on research productivity in universities.

Sub-hypothesis 1-1 Financial expenditures on remuneration will have positive effects on journal publications, book publications, patents, and licensing revenue.

Sub-hypothesis 1-2 Financial expenditures on performance-based payments will have positive effects on journal publications, book publications, patents, and licensing revenue.

Sub-hypothesis 1-3 Financial expenditures on research expenditures will have positive effects on journal publications, book publications, patents, and licensing revenue.

Sub-hypothesis 1-4 Financial expenditure on experiment expenditure will have positive effects on journal publication, book publication, patent, and licensing revenue.

Sub-hypothesis 1-5 Financial expenditures on machines and apparatuses will have positive effects on journal publications, book publications, patents, and licensing revenue.

Sub-hypothesis 1-6 Financial expenditures on books will have positive effects on journal publications, book publications, patents, and licensing revenue.

In addition, this study explores specific mechanisms of resources such as remuneration and performance-based payments with regard to research performance. Resources relating to professor labor is composed of remuneration and performance-based payments and the operation mechanism of these two variables differs. Academic remuneration tends to rise with seniority in the university. It has been reported that universities that pay their faculty more perform better (De Fraja et al. 2016). However, remuneration shows a diminishing marginal rate of return on research performance in a situation where remuneration grows with seniority, even to the point where productivity may fall with seniority. In contrast with remuneration, performance-based payments refer to bonuses based on performance; these are capable of boosting work motivation, increasing the performance of faculty with an increasing marginal rate of return (Auranen and Nieminen 2010). These combined theoretical perspectives are used to examine the following hypothesis:

Hypothesis 2 Remuneration and performance-based payments will have different associations with research performance.

Sub-hypothesis 2-1 Financial expenditures on remuneration will have positive effects on journal publications, book publications, patents, and licensing revenue with a marginal diminishing rate of return.

Sub-hypothesis 2-2 Financial expenditures on performance-based payments will have positive effects on journal publications, book publications, patents, and licensing revenue with a marginal increasing rate of return.

4 Materials and methods

4.1 Data

This study collected financial and research productivity data from 95 universities in Korea, from 2009 to 2017.[1] Of these 95 universities, 40 (42.11%) were in the capital area and 55 (57.89%) were in non-capital, regional areas. By number of students, 17 universities (17.89%) had less than 5000 students, 32 (33.68%) had 5000 to less than 10,000 students, and 46 (42.42%) had 10,000 students or more. Research expenditures and productivity may vary depending on whether universities have colleges of medicine or engineering. Of the universities included in this study, 61 (64.21%) had a college of medicine and 85 (89.47%) had a college of engineering. Data on these universities were gathered from the university information disclosure system and are shown in Table 2.[2]

4.2 Variables

4.2.1 Independent variables

This study examined the university funds statements to determine financial factors affecting research productivity. In university funds statements, expenditures consist of cost items such as remuneration, management and operating expenses, expenditures on research and students, and non-education expenses. It systematically and specifically lists the items spent on conducting university activities. Remuneration was used as a key variable considering the labor-intensive character of universities as a factor affecting research productivity. In addition, we considered performance-based payment as a determinant of research productivity (Hall and Van Reenen 2000) because if money is given to productive researchers, they may produce better results (Auranen and Nieminen 2010). This study also considered expenditures on research and research management that are indirectly invested in research. Facilities and physical resources available at universities also affect the number of publications (Allison and Long 1990). For example, Schuelke-Leech (2013) considered capital equipment expenditures an important study variable in explaining research productivity. Here, expenditures on machines and apparatuses are considered facilities and infrastructure resources.

This study used full-time faculty remuneration and bonuses and expenditures on research and research management, experiments, machines and apparatuses, and books as independent variables. Furthermore, we considered university size. Size is an important factor affecting research productivity in universities along with university finance, as many studies demonstrate that bigger universities tend to show higher educational productivity. For example, Lloyd et al. (1993) pointed out in a study on university mergers in Australia that small universities may be inefficient in organizational management due to high unit costs. Keiji and Cohn (1997) conducted a study on the economic size of private universities

[1] Unfortunately, we were not able to gather book data only from 2013 to 2017 due to limitations in data availability. It is a relatively short period as compared to other variables. However, we added this variable to our model for analysis.

[2] The URL for this site is http://www.academyinfo.go.kr/index.do?lang=en. Final access date is 08.08.2019. This site provides the data for only three recent years. Further data are available upon request from the Korean Council for University Education.

Table 2 Data and formulas used to determine research productivity of financial investment

Division	Detailed item	Formula
Independent variables	Remuneration (full-time faculty remuneration, per full-time faculty member)	Full-time faculty remuneration/No. of full-time faculty members
	Performance-based payment (full-time faculty performance-based payment(incentive), per full-time faculty member)	Full-time faculty performance-based payment/No. of full-time faculty members
	Research expenditure (expenditure on research and research management, per full-time faculty member)	Expenditure on research and research management/No. of full-time faculty members
	Experiment expenditure (expenditure on experiments, per full-time faculty member)	Expenditure on experiments/No. of full-time faculty members
	Expenditure on machines and apparatus (expenditure on machines and apparatus, per full-time faculty member)	Expenditure on machines and apparatus/No. of full-time faculty members
	Expenditure on books (expenditure on books, per full-time faculty member)	Expenditure on books/No. of full-time faculty members
Control variables	Region	Capital area, metropolitan/regional
	Number of students	Less than 5000 students, 5000–less than 10,000 students, 10,000 students or more
	Establishment of college of medicine	University with college of medicine, university without college of medicine
	Establishment of college of engineering	University with college of engineering, university without college of engineering
	Year of university	Year of university foundation

Table 2 (continued)

Division	Detailed item	Formula
Dependent variables	KCI (No. of publications in KCI journals, per full-time faculty member)	Journals registered with the NRF (National Research Foundation, including journals with pending registration) + other academic journals published in Korea/No. of full-time faculty members
	SCI (No. of publications in SCI-equivalent journals, per full-time faculty member)	SCI-equivalent/SCOPUS academic journals + other general academic journals published internationally/No. of full-time faculty members
	Books (No. of book publications, per full-time faculty member)	No. of book publications/No. of full-time faculty members
	Patents (No. of patents, per full-time faculty member)	No. of domestic patents/No. of full-time faculty members
	Licensing revenue (sum of licensing revenue, per full-time faculty member)	Sum of licensing revenue/No. of full-time faculty members

Table 3 Descriptive statistics of independent variables

Item	Mean	SD	Min	Max
Remuneration	60,612	30,778	18,870	250,885
Performance-based payment	12,276	13,637	0	69,861
Research expenditure	9598	9787	0	81,534
Experiment expenditure	4654	3316	594	22,279
Expenditure on machines and apparatus	7737	6862	259	63,165
Expenditure on books	2917	2272	0	23,875

Unit: KRW 1 thousand

in Japan and discovered that smaller universities were advantaged in terms of teaching and learning, but bigger universities were more economical in terms of research closely related to educational productivity. As such, this study used the university budget scale and number of students as control variables. Other control variables were the presence of a medical college or engineering department, the university region, and year of university foundation (See Table 2).

As shown in Table 3, among financial variables affecting research productivity, remuneration and performance-based payments take up a great portion compared to other variables. For example, the average remuneration per full-time faculty member was KRW 60,612 thousand (one dollar is equivalent to 1180 Korean won), with a minimum KRW of 18,870 thousand and a maximum KRW of 250,885 thousand. The average performance-based payment (bonus) per full-time faculty member was KRW 12,276 thousand, with minimum of KRW 0 and maximum KRW 69,861 thousand. The average expenditure on research and research management per full-time faculty member was KRW 9598 thousand, with a maximum of KRW 81,534 thousand (Table 3).

4.2.2 Dependent variables

While financial investment can be measured relatively easily and objectively using quantitative methods, university productivity is difficult to measure with high validity and reliability. As a result, researchers have used various indicators to measure productivity. Phillimore (1988) noted four aspects of research performance: output, impact, quality, and utility. In this study, output was the production of research findings. To analyze the effect or impact that such output has on its audiences, citations were deemed suitable. Quality is the merit of the research output, recognized with awards or prizes. Finally, the utility of research can be demonstrated with patents, licenses, and contracts. Many studies use the number of publications to measure research performance or productivity. However, this practice has been criticized because all research publications are given equal weight, regardless of their quality or impact. For example, Effendi and Hamber (1999) noted that the need to publish likely causes stress for individual researchers, thereby increasing the possibility that they produce less significant publications. Broad (1981) argued that paper inflation has become a fact of academic life; emphasis on the quantity of publications may lead to “salami slicing,” which is reproducing the same research outcomes by merely changing the titles. Despite these limitations, the number of publications is widely used to measure research productivity in higher educational institutions (Baird 1991; Crewe 1988;

Table 4 Descriptive statistics of dependent variables

Item	Mean	SD	Min	Max
KCI	0.549	0.330	0.000	2.188
SCI	0.235	0.261	0.000	2.096
Books	0.102	0.062	0.008	0.443
Patents	0.094	0.131	0.000	1.116
Licensing revenue	579	1145	0.000	18,237

Unit: no. of publications per faculty, no. of patents per faculty, KRW 1 thousand

Dundar and Lewis 1998; Golden and Cartensen 1992a, b; Graves et al. 1982; Rushton and Meltzer 1981). This study also measured research productivity using papers and publications as: the number of publications in KCI journals per full-time faculty member; the number of publications in SCI-equivalent journals, per full-time faculty member; and the number of book publications, per faculty member. In addition, other dependent variables analyzed included patents and licensing revenues. Recently, universities have been recognized as main contributors to commercial technology development (Etzkowitz and Leydesdorff 2003) and university patents and licensing have received growing interest from academic researchers and policymakers (Baldini 2006; Verspagen 2006). In this context, it is important to analyze the determinants of research productivity including patent and licensing revenue. Theoretically, it is meaningful to investigate the determinants of publication, patents, and licensing revenue because it will provide insights to understand the research productivity mechanism from output to utility (Phillimore 1988). Table 4 summarizes descriptive statistics for study dependent variables.

4.3 Model

Pooled Ordinary Least Squares (OLS) Regression was conducted first to analyze the effects of financial resources on research productivity. The model for analysis was as follows.

$$y_{it} = \alpha + \beta_i lnx_{it} + \varepsilon_{it}, \qquad i = 1, 2, 3, \dots, n \quad and \quad t = 1, 2, 3, \dots, t \qquad \text{model 1}$$

y is the university productivity vector, x is the financial resources vector.

Given the nature of the data, panel data regression could be conducted. Panel data regression combines cross-sectional and time-series data, which allows the analysis to explicitly consider the heterogeneity of panel entities. The model for panel data regression was as follows.

$$y_{it} = \alpha + \beta lnx_{it} + u_i + \varepsilon_{it}, \qquad i = 1, 2, 3, \dots, n \quad and \quad t = 1, 2, 3, \dots, t$$

y is the research vector, x is the resource vector.

To use panel data regression, hypothesis testing is first used to determine whether it is necessary to consider the time invariant characteristics of error term u_i. This can be done with the Breush-Pagan Lagrangran multiplier test, which tests $u_i = 0$ for all panel entities. If this hypothesis is accepted, the estimation is made using pooled OLS without considering the characteristics of the panel entities; but if rejected, the estimation is made using the fixed effects model. When panel data regression is selected through the Breush-Pagan Lagrangran multiplier test, a decision is made to use either the fixed or random effects model. The fixed effects model regards error term u_i as a parameter: the model is $y_{it} = (\alpha + u_i) + \beta x_{it} + e_{it}$ and it assumes the constant terms are different among panel entities and fixed. On the other hand, the random effects model assumes error term u_i is a random variable and estimates the model as $y_{it} = \alpha + \beta x_i + u_i + \mathrm{e}$. The Hausman test is conducted to select either the fixed or random effects model.

Economically, a university can be regarded as a labor-intensive organization because it invests resources or faculty labor to produce educational services (Winston 1999). Thus, the effects of financial investment on research productivity have a curvilinear (versus linear) relationship. The quadratic regression model can also be presented in the form of $\mathrm{b} = (X'\mathrm{X})'X'$ y. This study analyzed the effects of remuneration and performance-based payment on research productivity through the following model:

$$\mathrm{y_{it}} = \alpha + \beta_1 \ln\pi_{it} + \beta_2 \ln\pi_{it}^2 + \gamma_1 \ln\varphi_{it} + \gamma_2 \ln\varphi_{it}^2 + \delta lnx_{it} + u_i + \varepsilon_{it}, \qquad \text{model 2}$$

y is research vector, π is remuneration, φ is performance based payment, x is resource vector.

If correlations are found among research productivity variables, a different model is needed. There are diverse measures of research productivity and they may be interconnected. For example, more research publications may lead to greater patents, which may lead to more licensing revenue. As such, it was necessary to use the seemingly unrelated regression (SUR) model, as it estimates the system of equations. The SUR model is constructed in the following form.

$$y_{it1} = \alpha_1 + \beta_1 \ln \pi_{it1} + \beta_2 \ln \pi_{it1}^2 + \gamma_1 \ln\varphi_{it1} + \gamma_2 \ln\varphi_{it1}^2 + \delta \ln x_{it1}' + u_{i1} + e_{it1},$$

y is the research vector, π is remuneration, φ is performance based payment, x is the resource vector

$$y_{it2} = \alpha_2 + \beta_1 \ln \pi_{it2} + \beta_2 \ln \pi_{it2}^2 + \gamma_1 \ln\varphi_{it2} + \gamma_2 \ln\varphi_{it2}^2 + \delta \ln x_{it2}' + u_{i2} + e_{it2},$$

y is the research vector, π is remuneration, φ is performance based payment x is the resource vector

$$where \begin{bmatrix} u_1 + e_1 \\ u_2 + e_2 \end{bmatrix} \simeq \left[(o, f\left(\tau_u + \tau_e\right) \right] \qquad \text{model 3}$$

5 Results

To verify the stability of panel data, we performed Levin, Lin, and Chu (LLC), Im, Pesaran, and Shin (IPS), and Fisher unit root tests. In the case of the Fisher test, all variables except books were stationary. After the panel unit root test, we first conducted pooled Ordinary Least Square (Pooled OLS) regression to analyze the effects of resources on research productivity; these results are presented in Table 5.

Results of the Breush-Pagan Lagrangran Multiplier test rejected the null hypothesis at the 0.001 level, indicating the model considering the characteristics of panel entities was suitable. Next, results of the Hausman test to determine the suitability of either the

Table 5 Results of Pooled OLS estimation

	KCI	SCI	Book	Patent	Licensing revenue
Regional university	0.026	−0.077***	0.018**	−0.024**	−219.470***
	(0.029)	(0.020)	(0.009)	(0.010)	(70.884)
5000–less than 10,000 students	0.076**	−0.033	−0.001	−0.056***	−148.274*
	(0.035)	(0.024)	(0.012)	(0.012)	(85.199)
10,000 students or more	0.119***	0.033	−0.022*	−0.043***	−28.197
	(0.037)	(0.025)	(0.012)	(0.012)	(89.611)
University with college of medicine	−0.150***	0.140***	−0.032***	0.039***	195.115***
	(0.026)	(0.018)	(0.009)	(0.009)	(63.708)
University with college of engineering	−0.183***	0.062**	−0.011	0.062***	337.821***
	(0.036)	(0.025)	(0.011)	(0.012)	(88.716)
Year of university	−0.001**	−0.002***	−0.000*	−0.000	1.780
	(0.000)	(0.000)	(0.000)	(0.000)	(1.104)
Remuneration	0.127***	0.031	0.026**	0.056***	327.528***
	(0.033)	(0.023)	(0.011)	(0.011)	(81.213)
Performance-based payments	0.051***	0.005	0.010***	0.006*	42.670*
	(0.010)	(0.007)	(0.003)	(0.003)	(23.624)
Research expenditure	0.023*	0.056***	−0.004	0.027***	194.097***
	(0.014)	(0.009)	(0.005)	(0.005)	(33.666)
Experiment expenditure	−0.070***	0.025*	−0.015**	0.030***	107.326**
	(0.021)	(0.014)	(0.007)	(0.007)	(50.681)
Expenditure on machines and apparatus	0.009	−0.032***	0.003	−0.005	−12.644
	(0.018)	(0.012)	(0.006)	(0.006)	(44.173)
Expenditure on books	0.035*	−0.031**	0.007	0.013**	187.331***
	(0.019)	(0.013)	(0.006)	(0.006)	(45.973)
Constant	0.872	2.541***	0.377	−0.861***	−11,072.923***
	(0.950)	(0.651)	(0.303)	(0.314)	(2316.160)

***$p<0.01$; **$p<0.05$; *$p<0.1$

fixed or random effects model (based on null hypothesis cov(x_i, $u_i=0$) showed that the random effects model was suitable at the 0.001 level except the book.[3] Table 6 shows results of the random effects model.

After random effects model estimation, we used the SUR model to gain efficiency in estimation by combining information from different equations. The SUR model also provided information on relations among research productivity variables. First, the correlation coefficient of the residual for the regression model was examined (Table 7). Results showed KCI and books had a 0.555 model correlation; patents and licensing revenue had a 0.613 model correlation.

Regarding control variables, university size was a relatively poor predictor of research productivity in terms of KCI, SCI, books, and licensing revenue. Some authors insist that larger departments have greater research productivity (Kyvik 1995), as they lead to

[3] In the book variable, we were unable to reject the null hypothesis. However, we could not find consistent and significant variables in the fixed effect model. Table 6 provides the results of the random effects model.

Table 6 Results of random effect estimation

	KCI	SCI	Book	Patent	Licensing revenue
Regional university	0.020	−0.065	0.019	−0.010	−257.946*
	(0.046)	(0.043)	(0.012)	(0.020)	(154.140)
5000–less than 10,000 students	0.080	−0.049	−0.001	−0.065***	−209.443
	(0.054)	(0.053)	(0.015)	(0.025)	(187.229)
10,000 students or more	0.135**	0.031	−0.023	−0.045*	−58.359
	(0.058)	(0.056)	(0.016)	(0.026)	(199.657)
University with college of medicine	−0.153***	0.083**	−0.035***	−0.004	22.363
	(0.041)	(0.038)	(0.011)	(0.018)	(136.826)
University with college of engineering	−0.173***	0.060	−0.012	0.050*	304.889
	(0.059)	(0.059)	(0.015)	(0.028)	(210.103)
Year of university	−0.001	−0.002**	−0.000*	−0.000	−0.010
	(0.001)	(0.001)	(0.000)	(0.000)	(2.557)
Remuneration	2.044	0.500	−0.284	−1.424***	−7203.091**
	(1.281)	(0.837)	(0.372)	(0.411)	(3046.528)
Remuneration squared	−0.086	−0.015	0.014	0.072***	358.890***
	(0.059)	(0.038)	(0.017)	(0.019)	(139.325)
Performance-based payment	0.035	−0.174***	0.004	−0.073**	−692.157***
	(0.103)	(0.064)	(0.029)	(0.031)	(232.556)
Performance-based payments squared	0.000	0.012***	0.000	0.006***	48.366***
	(0.006)	(0.004)	(0.002)	(0.002)	(14.759)
Research expenditure	0.019	0.001	−0.005	−0.007	42.442
	(0.018)	(0.011)	(0.006)	(0.005)	(39.490)
Experiments expenditure	−0.077***	−0.057***	−0.019**	−0.013	−167.344**
	(0.028)	(0.020)	(0.008)	(0.010)	(71.132)
Expenditure on machines and apparatus	0.010	−0.031***	0.005	−0.008*	−42.622
	(0.019)	(0.010)	(0.006)	(0.005)	(35.044)
Expenditure on books	0.026	−0.030**	0.008	−0.003	29.890
	(0.024)	(0.014)	(0.008)	(0.007)	(51.013)
Constant	−9.697	1.562	2.180	8.468***	39,676.836**
	(7.343)	(4.897)	(2.144)	(2.399)	(17,796.240)
Wald test	86.89	146.52	26.51	175.82	100.97

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 7 Model of relations between dependent variables

	KCI	SCI	Books	Patents	Licensing revenue
KCI	1				
SCI	0.2226	1			
Books	0.5556	0.131	1		
Patents	−0.091	0.3373	−0.038	1	
Licensing revenue	−0.019	0.329	0.020	0.613	1

Breusch-Pagan test of independence: chi^2 (10) = 348.281, $p < 0.0000$

"intellectual synergy" or more interactions between department members. We did not find this process to be operating at the university level. However, study results indicated that university size was a strong negative predictor of average patents in that smaller universities (with less than 5000 students) were more productive in terms of patents.

We tested for the effect of university type by including a dummy variable in each of the research productivity measures. The results indicated that universities with a medical college showed higher SCI values, patents, and licensing revenue but lower KCI and book values. Previous research showed similar results in that universities with medical colleges had more patents and licensing revenue (Coupé 2003; Henderson et al. 1998; Siegel et al. 2003; Thursby et al. 2001). The research productivity of patents and licensing revenue in medical universities is associated with the rapid expansion of patents in medicine and pharmaceuticals revenues (Heisey and Adelman 2011). For example, Pressman et al. (1995) reported that over 60% of university licenses were from biomedical inventions. Results for universities with engineering colleges were similar (Owen-Smith and Powell 2003). As such, it is plausible to assume that Korean universities with medical and engineering colleges are well-suited to international research, patents, and licensing revenue and are the main drivers of applied research and academic engagement. The year universities were founded showed conflicting results. More recently established universities were less productive in KCI, SCI, and books but more productive in licensing revenue. It is likely that newly established universities are more proactive in academic commercialization.

As a result of estimation, we found that research expenditures showed significant for SCI, patents, and licensing revenue, indicating that greater university spending yields greater research productivity in these three areas. In this study, research expenditures imply money for graduate students, research materials, and travel (Schuelke-Leech 2013). Generally, R&D expenditures have been used as determinants for academic patents (Azagra Caro et al. 2003; Coupé 2003; Payne and Siow 2003) and provide evidence that well-funded faculty tend to be more productive (Coupé 2003). Similar to previous studies, we found that research expenditure was statistically and positively associated with SCI, patents, and licensing revenue. Experiment expenditure was the resource for experiments and empirical research. Somewhat surprisingly, we found a significant negative association with this variable for KCI and books. It is possible that the nature and process of KCI and books are different from the other productivity measures. In addition, KCI and books may have been affected by other factors, such as individual attributes and omitted variable bias.

Expenditure on machines and apparatuses showed different results from other independent variables. Machines and apparatuses are types of physical resources assumed to be necessary for empirical research and to maintain a stimulating professional environment (Schuelke-Leech 2013). Different from this assumption, KCI was the only productivity measure significantly affected by this variable. Lastly, library expenditures were expected to be positively related to research productivity measures. However, only patents and licensing revenue showed positive and significant values. Results for KCI, SCI, books, and library expenditures were different from those of previous research (Rushton and Meltzer 1981; Dundar and Lewis 1998).

In addition, we found that remuneration and performance-based payments were closely associated with SCI, patents, and licensing revenue. These results showed that research productivity, as measured by SCI, patents, and licensing revenue, increased when full-time faculty remuneration increased, but the law of diminishing returns was evident. However, performance-based payments showed opposite results, which helps understand the faculty response to financial investment. Expenditures on research show significant values in SCI, patent, and licensing revenue. However, experiment expenditures show conflicting results

Table 8 Results of SUR model estimation

	KCI	SCI	Books	Patents	Licensing revenue
Regional university	−0.054	−0.058**	0.018*	−0.009	−31.765
	(0.048)	(0.029)	(0.009)	(0.013)	(94.890)
5000–less than 10,000 students	0.037	0.012	−0.002	−0.043***	−21.903
	(0.062)	(0.037)	(0.012)	(0.016)	(121.569)
10,000 students or more	0.089	0.054	−0.024*	−0.034**	30.166
	(0.063)	(0.038)	(0.012)	(0.017)	(124.656)
University with college of medicine	−0.124***	0.177***	−0.034***	0.055***	177.802**
	(0.045)	(0.027)	(0.008)	(0.012)	(87.551)
University with college of engineering	−0.186***	0.082**	−0.012	0.091***	465.123***
	(0.060)	(0.036)	(0.011)	(0.016)	(117.054)
Year of university	−0.001*	−0.002***	−0.000**	0.000	3.606**
	(0.001)	(0.000)	(0.000)	(0.000)	(1.474)
Remuneration	2.002	3.406***	−0.330	1.009**	7552.33**
	(1.531)	(0.914)	(0.290)	(0.403)	(3006.815)
Remuneration squared	−0.088	−0.156***	0.016	−0.044**	−328.563**
	(0.070)	(0.042)	(0.013)	(0.018)	(136.983)
Performance-based payments	0.207*	−0.224***	0.004	−0.103***	−1025***
	(0.125)	(0.074)	(0.024)	(0.033)	(244.658)
Performance-based payment Squared	−0.010	0.014***	0.000	0.006***	64.676***
	(0.008)	(0.005)	(0.001)	(0.002)	(15.016)
Research expenditure	0.021	0.077***	−0.005	0.042***	271.523***
	(0.025)	(0.015)	(0.005)	(0.007)	(49.255)
Experiment expenditure	−0.090**	0.041*	−0.017**	0.049***	180.417**
	(0.036)	(0.021)	(0.007)	(0.009)	(70.049)
Expenditure on machines and apparatus	0.061*	−0.008	0.003	0.010	−23.729
	(0.032)	(0.019)	(0.006)	(0.008)	(62.088)
Expenditure on books	0.030	−0.029	0.005	0.028***	290.185***
	(0.034)	(0.020)	(0.006)	(0.009)	(66.753)
Constant	−9.231	−15.278***	2.428	−6.617***	−52,220***
	(8.837)	(5.274)	(1.674)	(2.327)	(17,351.580)

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

according to research. We found that experiment expenditures show statistically significant but negative associations with KCI and book. Surprisingly, expenditure on machines and apparatuses were insignificant for all research except KCI (Table 8).

6 Discussion

This study examined the determinants of research productivity at 95 universities in Korea. This study provides important implications based on the SUR model. Interestingly, in SCI, patents, and licensing revenue, remuneration variables were positive while remuneration squared variables were negative. This indicates that, holding all other variables constant, the average productivity indexed by SCI, patents, and licensing revenue will initially increase as wages increase, but at a diminishing rate. With such results, it is logical to assume that beyond some remuneration, research productivity would fail to rise thereby reflecting the law of diminishing returns. These results are consistent with previous studies which focused on the dynamic nature of research productivity over the life cycle (Cole 1979; Stephan 1996). These studies explained how the life cycle may affect research productivity (Gonzalez-Brambila and Veloso 2007). They suggested that human capital investment declined over time which would lead individual productivity to follow an inverted U-shaped pattern, which is similar to this research. Even though the focus and unit of analysis were different, the productivity pattern found in this study was similar. One likely scenario is the compensation system: professors earn higher salaries over time. In contrast, the performance-based payment variable showed different results. The SUR model results indicated that the performance-based payment variable was a strong predictor of SCI, patents, and licensing revenue, similar to the remuneration variables. However, the performance-based payment variable had a negative sign and the performance-based payment square coefficient sign was positive. This means performance-based payments showed a U-shape pattern in SCI, patents, and licensing revenue indicating that, on average, these productivity indices will increase as performance-based payments increase. Until now, the importance of incentives on the generation of university research has been focused on patents and licensing revenue (Graves et al. 1982; Jensen and Thursby 2001; Lach and Schankerman 2008; Thursby et al. 2007). This study provides empirical evidence for the importance of incentives for SCI in addition to patents and licensing revenue. However, the specific type of incentives and results differ across studies. For example, Lach and Schankerman (2008) used royalty as incentive and showed that higher royalty shares to faculty scientists appeared to generate greater license income. They analyzed the influence of royalty shares and competitors' royalty shares on the license income. This study not only provides empirical information about the importance of incentives in research but also shows the incentive operating mechanism on research productivity indices, such as SCI, patents, and licensing revenue. These finding have important implications for university policy. Specifically, to enhance their research productivity, universities must invest their resources in performance-based payments rather than remuneration.

This research provides insight into university resources and research productivity. Through these analyses, we can examine the marginal production of an additional investment. Especially, we found that remuneration and performance-based payments affect research productivity differently. As universities increase remuneration to researchers, productivity in SCI, patents, and licensing revenue will increase, but at a certain level, the marginal product of an additional remuneration will begin to decline. However, it is important to note that performance-based payments show a pattern of marginal increasing productivity rates. The empirical evidence suggests that incentives have a real effect on research productivity. For high SCI performance, patents, and licensing revenue, it is desirable to invest resources into performance-based payments rather than remuneration. In this situation, it is necessary to adopt an effective incentive plan (Gibbs 2012) and to manage performance-based payments systematically. We need to develop a more complete performance evaluation model which reflects researchers' efforts, actions, and decisions with reasonable strength and accuracy.

Even though this study provides empirical evidence and implications for research productivity, it has some limitations. First, this study did not consider multi-authored problems in research performance. In every scientific discipline, the proportion of multi-authored papers is rising (Sonnenwald 2008). These phenomena can be explained with the development of communication technology, increase in researcher mobility and collaborative research program (Kumar 2018). The increase in multi-authored research should result in more publications and in better journal impacts (Sahu and Panda 2014). However, equal evaluation for single-author and multi-author research is not fair and causes unjust disproportions for research evaluation. Some studies have insisted that multi-authored article have a significant impact on enhancing institutions' positions (Cakir et al. 2019). There are many methods of weighing authorship that can distribute the credit more properly and suppress a tendency to inflate the importance of the co-authors unjustifiably. However, in this study, measured publications in KCI, Book, and SCI were not weighted for the number of co-authors or the number of co-authors from different institutions. Thus, these limitations may lead to potential bias in the research performance and its determinants. Further research that considers the multi-author problem and its impacts is needed.

Second, an understanding of the influence of combined government and university funds on research productivity should be examined. Previously, many studies investigated the effect of government research funding on university research (Jacob and Lefgren 2011; Payne and Siow 2003) and the determinants of departmental research productivity (Baird 1991; Dundar and Lewis 1998). However, there is little empirical evidence with respect to the extent that government funding affects research performance in relation to university resources (Muscio et al. 2013). Third, even though research indicators are complex and multidimensional (Phillimore 1988), this study did not consider such issues. The determinants of patents and licensing revenue may be different from those of research publications. University technology transfer offices and royalty and patent policies may affect patents and licensing revenue (Heisey and Adelman 2011; Lach and Schankerman 2008). Thus, an understanding of relationships between research productivity measures should be fully examined. Lastly, financial investments in universities may have a time lag. Research productivity may be influenced by previous investments (i.e., a previous year's publication may affect the observed year's patents or the previous year's patents may affect the observed year's licensing revenue). To date, relationships between patenting and internal R&D activity have only been investigated in the commercial sector (Wang and Hagedoorn 2014). Future research should explore the lag structure between research investments and outcomes, including publications, patents, and licensing revenue in universities.

7 Conclusion

In increasingly competitive educational, research, and commercial environments, governments are implementing various policies to promote research productivity and universities are making great efforts to reinforce their competitiveness. In this context, it is imperative to understand what comprises university resources, how these resources relate to university research productivity, and how university resources affect education and research. This information makes it possible to efficiently utilize university finances and helps universities determine what evaluation indicators to use for financial or institutional support.

In this study we investigated the determinants of research productivity, focusing on resources by analyzing how university resources affect research in universities. Panel analysis estimated the effect of resources on research. Using the SUR model, we considered associations among research productivity variables and provided empirical evidence that SCI, patents, and licensing revenue are correlated. We found significant evidence that remuneration, performance-based payments, and research expenditures were strong predictors of SCI, patents, and licensing revenue. In addition, we tested whether the relationship between remuneration, performance-based payments, and research productivity were nonlinear by examining the squared remuneration and performance-based payments. Results of the quadratic form regression showed that research productivity indices (SCI, patents, and licensing revenue) increased when full-time faculty remuneration increased, but there was the law of marginal diminishing returns. In contrast, the performance-based payment variable showed the opposite or the law of marginal increasing returns. Unlike SCI, patents, and licensing revenue, we found that resource variables were insignificant or contradicted our assumption for KCI and books. These findings suggest that knowledge generating processes differ according to research products, and different factors may affect performance.

This study enhances the understanding of factors affecting research productivity in Korean universities. Findings from this analysis are important for policy makers and university administrators. For policymakers, this research provides empirical information about the way to promote research productivity. This knowledge can be used to allocate resources to allow university officials to align specific resources for enhancing research productivity. University administrators could increase research productivity directly by changing the levels and composition of research expenditures. Additionally, this study raises further issues in need of research. The study of research performance with authorship-weighed counting schemes is needed. In addition, it is necessary to analyze the factors affecting research productivity using data from both government funding and university resources. It is important to examine the dynamic nature of research productivity. Lastly, relationships between resource investment, publications, and applied research are not well understood and should be examined. This is particularly important given the need to prioritize the allocation of limited resources in changing academic, social, and commercial environments.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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