Science and Public Policy, 46(2), 2019, 219–231
doi: 10.1093/scipol/scy052
Advance Access Publication Date: 10 August 2018
Article

The unintended consequences of performance-based incentives on inequality in scientists' research performance

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Abstract

The reward system in academic science has changed rapidly in recent years, as many universities especially in Asia and Europe implemented new incentive systems based on research performance. To understand the relationship between inequality in science and the performance-based incentives, this study examined the influence of incentives for publications on not only research performance, but also the distribution of research performance in a Korean university. The findings of this study suggest that using a carefully designed performance incentive system, research organizations may reduce inequality in scientists' research performance while increasing their overall performance. The reduced inequality was due mainly to lower ranking researchers improving their publication performance. Meanwhile, top-ranked researchers responded only to incentives for the quality of publications. We interpret the change in research performance as an outcome of complicated interactions among the structure of incentive systems, scientists' diverse motivations, and their position in the stratification in science.

Key words: inequality in science; performance-based incentives; research performance; reward structure; incentives for publication.

1. Introduction

In the scientific reward systems in academia, one of the new phenomena we witness is the increase in performance-based incentives (Hicks 2012). Universities under pressure from the increased political demand for accountability and the growing competition for higher positions in national and global university rankings have designed and implemented new reward systems to promote research performance among their faculties (see Whitley and Gläser 2007). In particular, a number of Asian and European universities where faculties traditionally received the same salary regardless of their research performance have recently introduced performance-based incentives to complement their traditional seniority-based salary systems (Gleditsch 2007; *Nature* 2006; Stephan 2012). Increasing evidence indicates that financial incentives for publications have induced changed behavior of scientists. For example, the incentives affect scientists' decision about where to submit articles for publications and how many (Andersen and Pallesen 2008; Franzoni, Scellato, and Stephan 2011; Kim and Bak 2016). Notwithstanding, there have been relatively few empirical studies that delved into the influence of such performance-based incentives on the structure of academic science, such as inequality in scientific performance (Beerkens 2013; Suárez and Dutrénit 2015).

The tension between equity and efficiency has long been a central concern in public policy (Hicks and Katz 2011). In particular, science has been described as an institution with extreme inequality in terms of scientific performance and the allocation of rewards (Price 1986; Stephan 2012). The distribution of research performance across scientists has tended to be highly skewed. Lotka's law and Price's law suggest that in most disciplines, about half of published papers can be attributed to about 6 percent of scientists who publish consistently (Price 1986; see also Albarran et al. 2011). Extreme inequality in research performance also relates to extreme inequality in rewards in science. The scientific community consists of different categories of researchers in a hierarchical elitist structure, as demonstrated through the difference in reputation and resources between Nobel Laureates and rank-and-file researchers. The proponents of the current system of science have tended to claim that the hierarchical structure of science or stratification in science is necessary for efficiently distributing valuable resources to researchers who are more able and motivated to produce innovative knowledge (Cole and Cole 1973; Merton 1973).

The sociology of science has traditionally focused on the relationship between the reward system and inequality in science, emphasizing cumulative advantage as the mechanism that produces and reinforces the inequality in science (Merton 1973). In addition, research on the stratification of science has long demonstrated that particularistic factors other than scientific merits of a research, such as gender, race, graduate advisors, and prestige of universities bestowing a doctoral degree, influence the ways in which scientists' research outcomes are evaluated and recognized by their colleagues (Allison and Long 1990; Long and Fox 1995). Given their long scholarly interest in the social mechanisms to explain inequality in science, it is surprising that sociologists have been paying little attention to the influence of recent changes in the reward systems in academic science, such as the introduction of performance-based incentives, on inequality in research performance or stratification in science.

In contrast, science policy studies have examined the influences of recent changes in the reward systems in science. For example, much research has analyzed the effects of the introduction of performance-based incentives on the research performance (Abramo et al. 2011; Butler 2003; Kim and Bak 2016). Coinciding with the research governance reform in European and Asian countries (see Welpe et al. 2015; Whitley and Gläser 2007), however, these studies tended to focus on performance management while ignoring the questions of inequality or stratification in science.

This study attempts to fill this gap by examining the relationship between the performance-based incentives and the distribution of research performance in a Korean university, which has in the last decade significantly increased its provision of financial incentives for each faculty member's publication. Obtaining panel data on each faculty member's publication from 2004 to 2012 allowed us to take advantage of fixed-effect panel data models to examine the ways in which such external incentives influence the distribution of the research performances among faculty members while controlling for all time-invariant factors, such as gender, educational background, and disciplines. In this study, scientists from the fields of natural science, engineering, and medical science were studied together rather than separately for each discipline or field. Instead, we categorized different groups of scientists by the level of their publication performance and tried to identify groups most influenced by the increase in the performance-based incentives. In doing so, we attempted to understand the potential influence of performance-based incentives on the structure of academic science beyond individual scientist's research performance. That is, this study focuses on the impact of incentives on inequality in research performance, *the unequal distributions of publications across different groupings of scientists*, rather than the impact on research performance *per se*.

This study also emphasizes that the influence of incentives on inequality in research performance may vary depending on scientists' responses to the incentives. Performance-based incentives have been widely perceived to accelerate inequalities in many areas by rewarding those with higher performance (Bacache-Beauvallet 2006; Besley and Ghatak 2003; Boyne and Hood 2010). However, the recent scholarship on the relationships between incentives and motivations suggests that the influence of incentives on job performance is complicated, because while the influence of incentives depends on the compatibility of the incentives with workers' values, people have different values and preferences (Frey 1997; Frey and Jegen 2001; Lam 2015; Langbein 2010; Lazear and Shaw 2007; Rainey 2014). We, therefore, hypothesized that the influence of performance-based incentives on inequality in research performance would be determined mainly by whether they inspire efforts among scientists with higher performance or those with lower performance. If the increase in such incentives stimulated primarily the performance of the top-ranked faculty members in the publication hierarchy, this would suggest that the performance-based incentives tend to reinforce the inequality in research performance. In contrast, if the increase in the incentives promoted the performance of the middle- or low-ranked faculty members rather than of the top-ranked faculty members, it would suggest that the incentive system might help reduce the inequality.

2. Incentives and inequality in scientific performance

2.1 Sociological perspectives on inequality in science

Academic science is highly stratified in terms of research productivity, rewards, and scientists' status (Albarran et al. 2011; Cole 1992; Cole and Cole 1973; Price 1986). Sociologists of science, especially in the USA, have attempted to explain the highly stratified structure of scientific performance using the concept of cumulative advantage instead of scientists' talent (Allison et al. 1982; Merton 1973). Cumulative advantage refers to an advantage of earlier career success in science, which 'tends to allow scientists to accrue recognition and resources that, in an increasing returns pattern mediated by higher productivity, lead to even greater recognition and access to resources' (Hess 1997: 59). It allows scientists of considerable reputations to attract greater funding and better personnel, which are in turn closely related to research performance. These scientists may also find it easier to have their work recognized by their colleagues because of their strong record of accomplishment and the status of the organization with which they are affiliated. Thus, their work might be more likely to be accepted in top journals (Allison and Long 1990; Allison et al. 1982; Crane 1972; Merton 1973).

Being concerned with whether differences in research performance are 'a result of the unequal distribution of resources and facilities' or 'an outcome of the unequal distribution of talent' (Cole and Cole 1973: 75), cumulative advantage theory calls into question the fairness of inequality in science. However, according to DiPrete and Eirich (2006), the earlier sociology of science has tended to advocate for cumulative advantage based on three premises. First, resources in science are limited. Second, it is difficult to observe scientists' research ability and evaluate their future performance. Third, the norms of universalism and communism are used to evaluate a scientist's research performance and allocate resources in science. In this way, inequality in scientific performance, rewards, and status attainment in science is justified as a meritocratic system in which the society distributes the resources to scientists who are most capable of producing valuable scientific knowledge (Cole 1992; Cole and Cole 1973; Gaston 1978; Merton 1973).

However, much criticism has emerged about the functionalist description of the structure of the scientific community. Empirical studies have emphasized that the particularistic factors, such as gender, nationality, social networks, and affiliated institutes of scientists, have influenced research performance, the process of evaluating research performance, and the allocation of resources and rewards based on evaluation results (Allison and Long 1990; Long and Fox 1995; Roissiter 1993). It is also noted that, even though rewards in science are distributed in accordance with universalism, cumulative advantage can still lead to undesirable consequences. Not only would chance events, such as "unequal luck in the draw of reviewers upon submitting a grant proposal for funding", result in a relative (dis)advantage for a scientist among competitors with the same talent but also scientists with greater reputations would get "greater rewards from work of the same quantity and quality" as those of scientists with less reputations (DiPrete and Eirich 2006: 282). In addition, cumulative advantage tends to accelerate and widen inequality in research performance over time.

These critiques, therefore, imply that some talented researchers might be disadvantaged in competition owing to their ascribed characteristics or performance in their earlier careers, regardless of their potential to contribute to science. Accordingly, scientific institutions may need policy measures for these researchers not to lose their potential and zeal for research because of the disadvantage resulting from their lower status in science. It is also suggested that when introducing a new reward system to enhance research performance, scientific institutions should consider both equity and efficiency, acknowledging the hidden costs of discouraging these potentially valuable researchers.

2.2 Performance-based incentives, research performance, and inequality

In recent years, academic science has witnessed significant changes in the reward systems, such as various financial performance-based incentives. Performance-based rewards have long been embedded in the reward systems at North American universities where professors' research performance has often been linked to their salaries and promotions. In contrast, Asian and European universities have only recently begun to consider research performance in their salary systems. Under the growing pressure from global competition among universities and so-called 'audit explosion' (Power 1999), many universities in this region have begun to introduce incentive systems linked to research performance both at the individual and the organizational levels. For example, in the reform of research governance, European governments have not only introduced performance-based research funding systems but also allowed universities and public research institutes to distribute financial incentives to individual researchers based on their research performance (Andersen and Pallesen 2008; Franzoni et al. 2011; Gleditsch 2007; see also Hicks 2012). Similarly, some universities and research organizations have provided 'cash-per-paper incentives' to individual scientists (*Nature* 2006).

These changes in the reward systems represent the emergence of performance management in academic science. In the last decade, therefore, science policy communities have paid attention to the influence of changes in the reward systems mostly on research performance and behavior of institutes (Aagaard 2015; Abramo et al. 2011; Beerkens 2013; Butler 2003). As universities, especially those in Asia and Europe, have shifted from a loosely-coupled professional bureaucracy to a principal-agent relationship (Wilkesmann 2015), managerial efforts to monitor academic activities through performance measurement and performance-based incentives have significantly increased at both university and state levels (Auranen and Nieminen 2010; Hicks 2012).

Advocates of performance-based incentives in research institutes assume that scientists are no different from people in other fields, and they will exert more time and effort to improving research if their research performances are measured and rewarded. This is based on a principal-agent theory in economics, where performance-based incentives are used to restrict agent's opportunistic behaviors and encourage him/her to work for the principal's goals. Despite much concerns about the unintended consequences or hidden costs of incentives, such as agent's gaming with the performance measures by salami publishing, self-plagiarism, self-citations, or effort replacement (Bak and Kim 2015; Haustein and Larivière 2015), empirical studies have shown that financial incentives could be effective in influencing research performance (Andersen and Pallesen 2008; Butler 2003; Franzoni et al. 2011; Kim and Bak 2016). For instance, by analyzing the relations between reward structure and the number of submissions of publications to the Journal of Science in thirty countries, Franzoni et al. (2011) concluded that the introduction of cash and career-based incentives was positively associated with an increase in paper submissions, with the influence of cash incentives being particularly strong. Kim and Bak (2016) also found that financial incentives had positive relations with research performance, as measured by the quantity and quality of SCI publications.

Much of research on the effect of performance-based incentives, however, has paid attention to the effects of the performance-based incentives on performance of research institutes or scientists as a group while ignoring the influence of incentives on inequalities among researchers mainly because policymakers or managers of research institutes or universities care mostly about overall performances, which is directly linked to the ranking, reputation, and research funds of the organization.[1] That is, this line of research has focused mostly on the managerial concerns, such as 'How can we measure performance?' and 'Does a new research policy yield intended effects on the studied organization?' (see Welpe et al. 2015).

In the fields of public administration and public policy, the trade-off between efficiency and equity has been a controversial topic with the introduction of performance-based pay system. The performance-based contract is likely to encourage the agent to strategically focus his resources and efforts on the most productive users, which may contradict the principal's objectives in terms of service quality or homogeneity of the provision of services (Bacache-Beauvallet 2006; Besley and Ghatak 2003; Boyne and Hood 2010). For instance, in the US federal job training programs that allocated funds to training agencies based on their performances, to compete for financial rewards, training agencies had temptation to concentrate their resources on the most productive or job-ready applicants rather than those most-in-need, which increased the gap between those with different conditions (Courty et al. 2011).

Similar logic can be applied to universities and research institutes with an audit culture and new public management movements. Under the pressure to raise their ranking and reputation, administrators of universities and research institutions are likely to motivate to move resources from less capable and unproductive researchers to the most capable and productive researchers, which is likely to widen the gap between them. Besides, referring to the aforementioned cumulative advantage theory, exceptional performance early in the career of scientists attracts new resources and accrues reputation that facilitates continuous high academic performance. Hence, the performance-based incentives possibly reinforce the pre-existing inequalities or stratification by giving extra resources to already high performing and resourceful researchers.

However, the influence of performance-based incentives on inequality in science can be more complicate, depending on how the incentive structure is designed and how scientists respond to it. Some evidence indicates that performance-based incentives may not necessarily increase inequality in research performance or strengthen stratification in science. Concerning motivation theories, for example, it is well known that incentives do not influence all workers with the same intensity or direction, because individuals are heterogeneous and vary in their preferences for different types of incentives (Barnard 1938; Langbein 2010; Lazear and Shaw 2007; Rainey 2014). First, workers' perception of incentives matters. Scientists have often been viewed as highly internally motivated to conduct research to satisfy their intellectual curiosity and academic interests rather than to pursue external rewards, such as monetary rewards or promotion to the higher position (Benz and Frey 2004; Deci et al. 2001). In his motivation crowding theory, Frey argued that if the internally motivated people perceive external rewards as controlling, those rewards may undermine (or crowd out) intrinsic motivations and reduce work efforts owing to impaired self-determination and self-esteem. External intervention is likely to crowd in and positively influence internally motivated individuals only if they see those interventions as supportive of their choices and values (Andersen and Pallesen 2008; Frey 1997; Frey and Jegen 2001; Lam 2015).

Second, workers have different perceptions of the relative value of money to the value of the job, and those who value their job are likely to accept salary-based work at lower pay when compared with those who prefer the risk and potentially larger return from pay-for-performance salary system (Langbein 2010; Lazear and Shaw 2007). According to Stern's (2004) study, scientists could balance their preference and productivity. High-quality scientists tend to place high values on hedonic characteristics and science-oriented environment; they are willing to sacrifice their pay to work on valuable projects.

Finally, the reward structure and types of incentives influence people's motivation and performance. Bohnet and Oberholzer-Gee (2002) conducted a survey with more than 100 companies in Switzerland about relations between the reward structure and the quantity and quality of employees' suggestions. They found that, as the total sum of rewards increased by Sfr 1,000 per year, employees submitted about three additional ideas on an average, but the quality of ideas did not improve. On the other hand, when the company raised the reward for the best ideas by Sfr 1,000, the number of ideas decreased. The authors argued that the minimum rewards encouraged less talented employees to choose to participate; thus, 'selection effects' outbalanced 'motivational effects', which tend to motivate only the most talented employees who can reasonably compete for the prize (Bohnet and Oberholzer-Gee 2002).

In sum, inequalities among research scientists are likely to either increase or decrease, depending on the interactions among the reward structure, scientists' preferences, and types of incentives. In the following sections, we explore this question using the empirical data collected at a Korean university.

3. The reward system at Korean universities

The reward system at Korean universities has been characterized by the seniority-based system in which the annual salary of the faculty is determined according to seniority and increases at the same rate regardless of faculty members' discipline or research performance. However, the increasing emphasis on faculty research has led Korean universities to change the reward systems to promote research performance among faculty members. The emphasis on research in Korean universities is a relatively recent phenomenon. In the 1960s and 1970s, the Korean government viewed universities primarily as educational institutions and provided minimal support for academic research. Since the late 1980s, the Korean government has rapidly increased its support of university research, including large-scale, long-term national R&D projects aimed at developing fundamental technologies. As a result, the university R&D expenditure spending in 2010 was 44.5 times greater than that in 1980 and 8.7 times greater than that in 1990, even after controlling for inflation (NSTC 2012). Since the previous research performance of professors is perceived as the most important factor in obtaining more government funds, faculty performance in scientific research has become increasingly important for the revenues and reputations of universities.

Another important motivation for increasing the emphasis on faculty research is the growing prominence of national and global university rankings (Espeland and Sauder 2016). Although the Korea Council for University Education has been rating Korean universities and departments since 1982, the university ranking tables began to receive much media attention only in the mid-1990s. The newspaper company *JoongAng Daily* has been publishing the university and department rankings annually since 1994. These ranking tables have considerably influenced the reputations of Korean universities mainly because this particular newspaper, being the second largest circulation in Korea, has actively publicized the ranking table. In addition, the increasing popularity of global university rankings in this period has also driven many Korean university administrators to improve their ranks. These changing environments have pushed academic researchers to increase research productivity and publish research findings in international journals.

With the increasing emphasis on faculty research in Korea, the university we studied strengthened the 'cash-per-paper incentives' to stimulate faculty research.[2] Faculty members in the science, engineering, and medical fields receive cash incentives for each paper they publish in journals with SCI index. Originally, the university has been offering some compensation (about $200) for the costs incurred for journal publications, such as offprints and English editing services, since the 1990s. In the last decade, however, the university under the investigation has significantly increased financial incentives for international journal publications. For example, its cash incentives for each paper published in SCI journals increased from approximately $400 in 2000 to $2, 200 in 2012 (see Fig. 1). The first author or the corresponding author oversees the distribution of the incentives to co-authors at his/her own discretion. Since 2003, the cash bonuses have been adjusted also based on the journal's impact factor. In particular, substantial cash bonuses have been provided for articles published in leading international scientific journals. Thus, increased cash incentives have complemented the traditional seniority-based salary system.[3]

4. Data and method

4.1 Data and variables

We collected the administrative data on the research performance of 450 professors who stayed at the studied university for 9 years between 2004 and 2012. To see the changes in the level of inequality among the same group of scientists, we excluded retired and newly hired professors from the sample, yielding 4,050 observations where the unit of analysis was aggregated per professor i and year t, with 'i, t'. All professors were from the fields of natural science, engineering, and medical science. The research performance was measured by the quantity and quality of publications in SCI journals. The number of publications was adjusted based on the number of

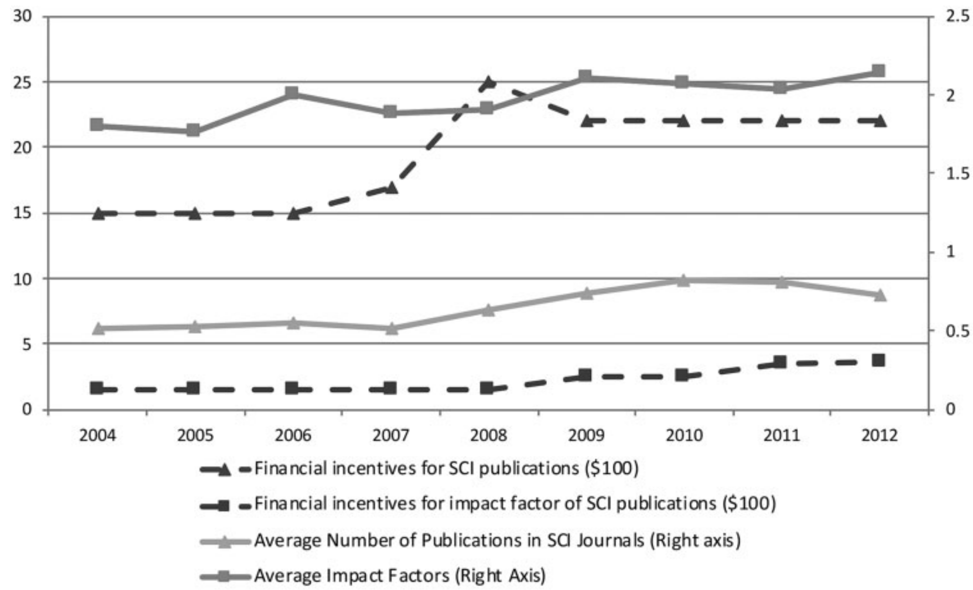

Figure 1. Changes in financial incentives for each journal article, a one-unit increase in impact factor, changes in the average number of publications in SCI Journals, and the average impact factors published in SCI Journals (2004–12).

Table 1. Descriptive statistics.

Description	Obs.	Mean	Std. Dev.	Min.	Max.
Dependent variables					
A total number of publications in SCI Journals adjusted for the number of authors per professor and year, *i*, *t*.	4,050	0.65	1.21	0.00	19.26
Average impact factors in SCI Journals per professor and year *i*, *t*.	2,220	1.97	1.30	0.03	14.82
Independent variables					
Financial incentives for the number of publications ($100)	4,050	19.44	3.69	15.00	25.00
Financial incentives for impact factors ($100)	4,050	2.20	0.83	1.50	3.67
The minimum requirements for promotion (a number of SCI publications adjusted for the number of authors per year)	4,050	0.17	0.32	0.00	1.00
The proportion of untenured professors	4,050	0.29	0.45	0.00	1.00

co-authors.[4] Since our case university has used journal impact factors as a criterion for incentivizing research quality, we also use the impact factor of the journal in question as a measure of publication quality. While debates about whether impact factors and number of citations are a valid measure of research quality continue, impact factors have long been used as such an indicator (Stephan and Levin 1991).

Table 1 presents descriptive statistics for our variables. On an average, each professor published 0.65 papers per year after adjusting the number of co-authors. Top 10 percent professors, as ranked by the number of SCI publications over 9 years, published almost three papers per year (=2.96) in SCI journals, almost triple as much as an average number of publications of professors in 70th–90th percentile (=0.98). Every year, about 38 percent of professors did not have any publications in SCI journals. The average impact factor of 2,220 observations with at least one SCI publication was 1.97, ranging from 0.03 to 14.82. On an average, about 72 percent of observations (=2,891) were from tenured professors, and the proportion of tenured professors increased from 57 percent in 2004 to 86 percent in 2012 as assistant and associate professors became tenured ones over time.

The studied university provides additional financial incentives, in addition to a base salary, to a professor for publishing a paper in the SCI journals, adjusting for impact factors of the journals where the paper is published. Figure 1 indicates the changes in financial incentives for the number of publications and their impact factors. The university has raised financial incentives for each publication in SCI journals from $1,500 in 2004 to $2,500 in 2008. After the peak in 2008, the incentives have been slightly reduced to $2,200 in 2009 and thereafter.

The reward structure is more complicated for the quality as opposed to the quantity of publication. In general, the amount of the quality incentive was determined as a product of the impact factor and the amount of the incentive. The financial incentives per one impact factor score have gradually increased from $150 in 2004 to $250 in 2009, and again, to $370 in 2012. Thus, the quality incentive for the paper published in the journal with an impact factor of 2.0 was $740 ($370 × 2.0) in 2010. In addition, between 2004 and 2008, a cash reward of $10,000 was given to professors for the publication in top journals, such as *Nature, Science, and Cell*, increasing to $60,000 in 2009. As of 2011 the university has also increased the amount of cash reward to $500 per one impact factor score for publications in journals with impact factors of 4 and higher and offered $30,000 for publications in journals with impact factor of 20 and higher. Considering the complicated reward structure, we created the expected financial incentives, showing a gradually increasing pattern in Figure 1.[5]

Figure 1 also shows the changes in the average number of publications in SCI journals after adjusting for the number of authors and average impact factors of SCI journal publications. The average number of publications in SCI journals has risen from 2007 to 2010 while the financial incentives have increased. The average impact factors for SCI journals also increased gradually while the financial incentives for impact factors expanded. Overall patterns in Figure 1 support the previous findings that have reported positive associations between financial incentives and research performances.

To control for confounding effects, we included two additional variables. First, we created a variable reflecting the minimum number of SCI publications necessary to achieve promotion. The minimum number of SCI publications required for promotion of untenured professors increased from 0.3 per year in 2004 to 1.0 per year in 2008. Second, we included a dummy variable indicating whether a faculty member is tenured, based on the assumption that untenured professors work under different research conditions and face different pressures for performance compared to tenured ones. We assumed that this variable will be associated with research performance.

4.2 Analysis strategy

To examine the change in inequality of research performance over time, first, we calculated GINI coefficients for the number of publications in SCI journals and their impact factors. The GINI coefficient is a single-number summary of inequality, which measures the extent to which the distribution of income among individuals or households deviates from a perfectly equal distribution. The index ranges from 0, representing perfect equality, to 1, representing perfect inequality. We describe the change in GINI coefficients of SCI publications and their impact factors among the same 450 professors and assess their trend over 9 years.

Second, we present the change in the share of publications by four groups of professors based on a total number of publications in 9 years: top 10 percent, 70th–90th percentile, 50th–70th percentile, and 0–50th percentile[6]. We expected that, with increased financial incentives, the change in the group's share of publications will provide information about the change in performance of the group relative to others. Regarding impact factors, we calculated the average impact factors for all professors for each year (= yearly means) and divided the average impact factors by group in the top 10 percent, 70th–90th percentile, 50th–70th percentile, and 0–50th percentile for every year by the means for each year.[7]

Finally, using multiple fixed-effect panel data models, we estimated the influence of financial incentives on research performance within subgroups classified by research performances, as indicated earlier.[8,9] For each group, we regressed publication quantity in a given year against the one-year-lagged financial incentives, assuming that it takes approximately 1 year for these incentives to take effect in the form of a journal publication (Franzoni et al. 2011).[10] All specifications included professor- and year-fixed effects to capture unobserved professor characteristics and temporal effects. By subtracting professors' average characteristics across time, the fixed-effect model controlled for professors' unobserved and time-invariant characteristics, such as educational background, gender, and major. We also included year dummy variable in all specifications, although it is not reported in the estimate tables. Furthermore, we included the tenure dummy and the promotion requirement variables. The number of publications was a continuous rather than a count variable after adjusting for the number of coauthors; hence, OLS (Ordinary Least Squares) regression was used for the analysis instead of a negative binomial method (see Endnote 4). We took the log of the number of publications to normalize the right-skewed data. We conducted multiple fixed-effect data analyses for the quality of publications by the same four subgroups.

5. Results

5.1 The change in GINI coefficients of research performance over time

Figure 2 shows the changes in GINI coefficients for the number of publications in SCI journals and impact factors. The average GINI coefficient for SCI publications over time was 0.70, which has gradually declined from 0.75 in 2004 to 0.68 in 2012. Particularly, it has notably dropped from 0.75 in 2007 to 0.66 in 2009, and since then, it remained stable, between 0.66 and 0.68. Thus, GINI coefficients seemed to move in the opposite direction when compared with financial incentives over time. Specifically, as financial incentives increased, the gap in the quantity of research performances among researchers declined. We also examined changes in GINI coefficient for tenured professors to determine the changes in inequalities while controlling for changes in promotion requirement. The pattern that emerged was the same as that for all professors (please see a dotted line in Fig. 2).

The GINI coefficient of average impact factor of SCI journals was lower when compared with that of the number of publications. The average of GINI coefficient was 0.33, and it has decreased slightly from 0.37 in 2004 to 0.31 in 2012. The notable drop was from 0.40 in 2006 to 0.26 in 2009, and it rebounded to 0.31 in 2012. As described earlier, financial incentives for the quality of publications have gradually increased over time while major changes occurred in 2009 and in 2011. We believe that the declining trend between 2006 and 2009 reflects a dramatic expansion of the number of SCI publications while the increase in inequalities after 2009 can be explained by the change in financial incentives for the quality of publications, particularly various magnitudes of cash reward distributed based on journals' impact factors. The pattern of tenured professors that emerged was the same as that for all professors (please see a dotted line in Fig. 2).

5.2 The change in the quantity and quality of publications by subgroup

Figure 3 describes the changes in the share of SCI publications by researchers in the top 10 percent, 70th–90th percentile, and 50th–70th percentile, and 0-50th percentile of their research productivities. Between 2007 and 2009, while the total number of publications dramatically increased and GINI coefficients declined markedly (see Figs. 1 and 2), the share of publications by the researchers in the top 10 percent decreased from 0.57 to 0.48. In contrast, during the same time, the share of publications by the researchers in the 50th–70th percentile increased from 0.12 to 0.14. The share of publications by 70th–90th percentile researchers did not change much. In addition, during our research period, the contribution of the top 1 percent of researchers declined by 10 percent,

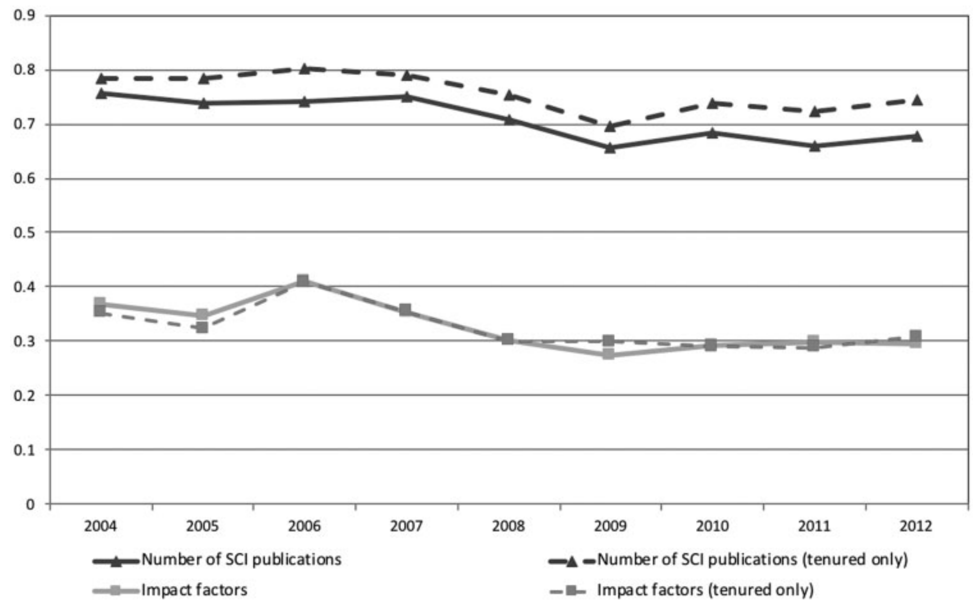

Figure 2. Changes in GINI coefficients for the number of publications in SCI Journals and average impact factors of SCI Journal Publications (2004–12).

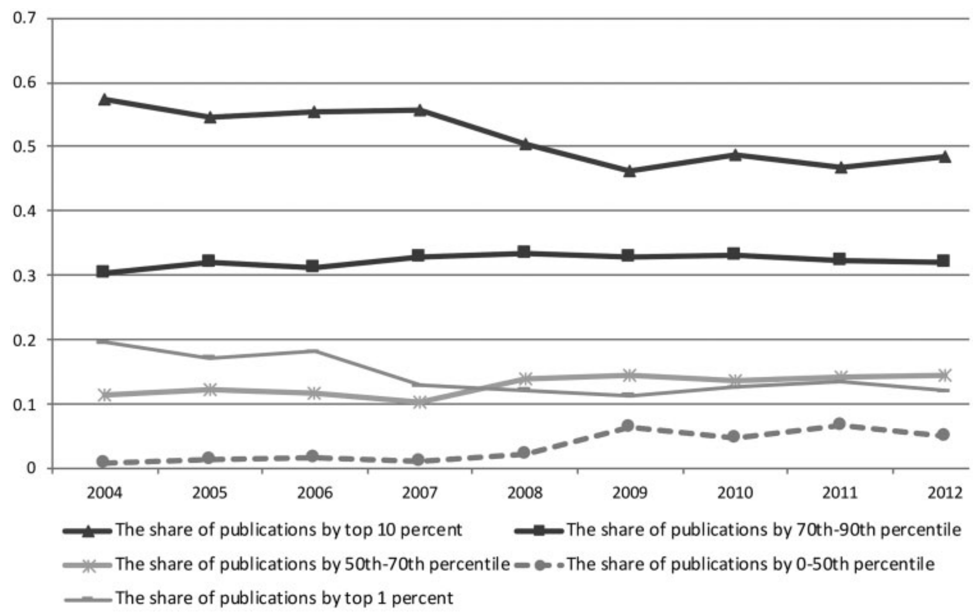

Figure 3. Changes in the share of SCI Publications among researchers in top 10th percentile, 70th–90th percentile, 50th–70th percentile, and 0–50th percentile (2004–12).

from 0.20 in 2004 to 0.11 in 2012, while the proportion of researchers without publications also decreased from 0.46 in 2004 to 0.32 in 2012, which means that over 9 years, the number of professors who published at least one paper increased by about 63. Overall, the gap in the share of publications across different level of performance groups declined over time. The trends imply that the increased number of publications between 2007 and 2009 can be explained mostly by increased number of publications by researchers in the 50th–70th percentile category and those who shifted from zero publications to some publications. Noticeably, the researchers in the top 10 percent did not seem to contribute to the increased pattern of SCI publications.

Figure 4 shows changes in the average impact factors of SCI publications by researchers in the top 10 percent, 70th–90th percentile, and 50th–70th percentile, and 0-50th percentile divided by the means for each year for all professors. The impact factor of the top 10 percent relative to yearly means had a V-shape; specifically, it declined from 2.40 in 2006 to 1.68 in 2009 and then increased after 2009. The impact factor of 70th–90th percentile relative to yearly means of all professors remained steady around 1.0 over time although it increased slightly after 2009. The pattern for professors in the 50th–70th percentile was very similar to that of 70th–90th percentile; specifically, it was around 0.5 between 2004 and 2009, increasing after 2009. The impact factor of the top five researchers relative to yearly

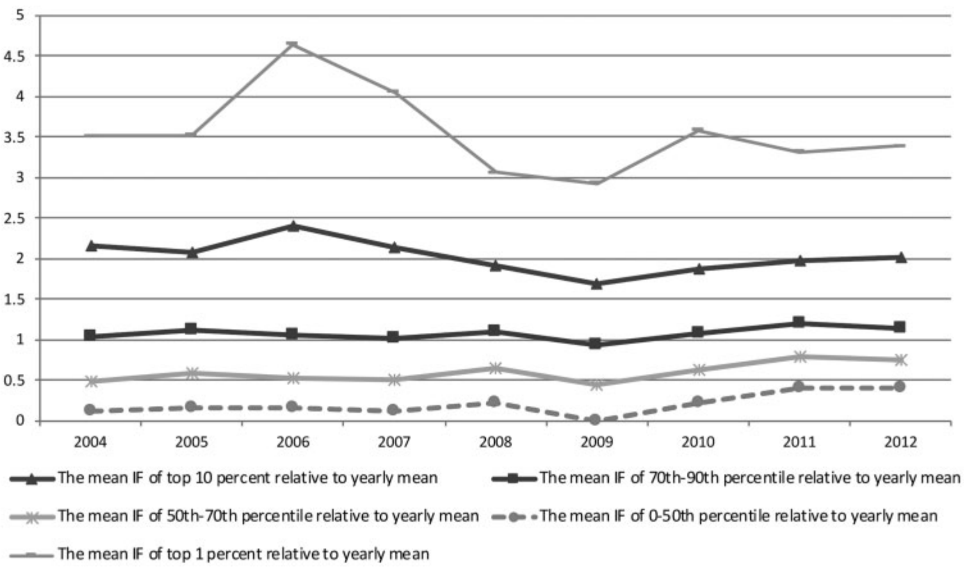

Figure 4. Changes in the mean impact factors for researchers in top 10th percentile, 70th–90th percentile, 50th–70th percentile, and 0–50th percentile relative to yearly mean (2004–12).

means of the sample shifted dramatically. It has plummeted from 4.64 in 2006 to 2.92 in 2009, increasing to 3.38 in 2012. Overall, from 2004 to 2009, the quality gap among top researchers and others diminished but, as of 2009, the degree of inequality did not change much in spite of adopting a more complicated and categorized reward structure.

5.3 The influence of financial incentives on research performance by subgroup

Table 2 presents the results of fixed-effect OLS analyses using subgroups with top10 percent researchers in Model (1), 70th–90th percentile researchers in Model (2), 50th–70th percentile in Model (3), and 0–50th percentile in Model (4). For each subgroup, we estimated the influence of financial incentives on the number of publications, controlling for the effects of the incentives based on impact factors, requirements for promotion, and tenure. In Model (1), the regression coefficient of financial incentives was not significant at 0.05 level, which implies that the top 10 percent researchers' research outputs did not change significantly in response to the change in financial incentives. In Models (2), (3), and (4), the regression coefficients of financial incentives are positive and significant at 0.001 level, which indicates that as financial incentives increased, the number of publications of the subgroups increased. In Model (2), which included researchers in the 70th–90th percentile, the regression coefficient was 0.174, which means that the number of papers increased by 19 percent ($=100*(\exp^{0.174}-1)$) percent for every \$100 increase in financial incentives, holding other factors constant. The average number of publications for this group was 0.98; hence, the number of papers increased by 0.18 for every \$100. The size of regression coefficient was largest in Model (3), with 50th–70th percentile group having a coefficient of 0.463, implying that for each \$100 cash reward, the number of papers increased by 59 percent ($=100*(\exp^{0.463}-1)$). Since the average number of papers in this group was 0.47, the number of papers increased by 0.28 for each \$100. Finally, in Model (4), which included researchers below 50th percentile, the regression coefficient was 0.316, indicating that for every \$100 increase, the number of papers increased by 37 percent ($=100*(\exp^{0.316}-1$). For researchers below 50th percentile, the average number of publications was 0.13; thus, the number of papers increased by 0.04 for every \$100.

Table 3 reports the results of multiple fixed-effect OLS models on the relations between financial incentives and the quality of publications using the same subgroups. In Model (1), which included top 10 percent of researchers in terms of the average journal impact factor scores of their publications in a given year, the regression coefficient of incentive was positive and significant at 0.01 level, meaning that as cash rewards for the quality of publication increased, the average impact factors of publications improved. In the other Models, the regression coefficients of the incentives for the quality of publications were not significant, implying that the cash rewards failed to encourage researchers in those groups to advance the quality of research.

6. Discussion

This study analyzed the influence of a performance-based financial incentive system on inequality in research performance and demonstrated varying responses to the incentives among diverse strata of researchers. Its effects on inequality in research performance is unintentional, because the incentive system was not designed to influence inequality in research performance. Yet, whereas the performance-based incentives have been often perceived to increase social inequality (Bacache-Beauvallet, 2006; Boyne and Hood 2010), this study suggests that a carefully designed performance incentive system, albeit introduced mainly to enhance research performance, may also reduce inequality in research performance. The findings of this study are particularly important because the improved equality was achieved with improved overall performance. How could it happen? Among many factors, the structure of the incentive system may help us understand the implications of the main findings of this study.

6.1 The importance of incentive structures

By suggesting the positive association between financial incentives and research performance, this study first raises a question of whether monetary incentives actually motivate scientists' research. Economists have recently claimed that in addition to satisfying

Table 2. The influence of financial incentives on the number of publications: groups by the number of publications.

OLS fixed-effect models: DV- ln (number of publications)

Variables	(1) Top 10%		(2) 70th–90th percentile		(3) 50th–70th percentile		(4) 0–50th percentile	
Financial incentives for the number of publications at $t-1$	0.001 (0.031)	0.000 (0.030)	0.175** (0.058)	0.174** (0.057)	0.469*** (0.112)	0.463*** (0.111)	0.315*** (0.067)	0.316*** (0.068)
Financial incentive for impact factors at $t-1$		0.085 (0.072)		0.146 (0.202)		0.723 (0.473)		−0.091 (0.369)
Promotion requirement at t	0.651 (0.976)	0.651 (0.976)	1.025 (0.983)	1.025 (0.983)	0.018 (1.853)	0.018 (1.853)	2.719 (1.548)	2.719 (1.548)
Tenure dummy (untenured = 1)	−0.545 (1.078)	−0.545 (1.078)	−0.893 (1.081)	−0.893 (1.081)	2.533 (1.767)	2.533 (1.767)	−0.619 (1.494)	−0.619 (1.494)
Constant	0.857 (0.766)	0.740 (0.828)	−4.583** (1.407)	−4.784** (1.595)	−15.003*** (2.527)	−16.000*** (2.816)	−18.445*** (1.390)	−18.320*** (1.476)
Observations	360	360	720	720	720	720	1,800	1,800
R^2	0.085	0.085	0.057	0.057	0.083	0.083	0.039	0.039
Number of id	45	45	90	90	90	90	225	225

Robust standard errors in parentheses. All models include year dummies.
$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$;
MODEL significance: F-test; coefficient significance: two-tailed t-tests.

Table 3. The influence of financial incentives on the impact factors: groups by the number of publications.

OLS fixed-effect models: DV-impact factors

Variables	(1) Top 10%		(2) 70th–90th percentile		(3) 50th–70th percentile		(4) 0–50th percentile	
Financial incentive for impact factors at $t-1$	0.308*** (0.063)	0.207** (0.062)	0.190 (0.108)	0.063 (0.094)	0.154 (0.123)	0.106 (0.072)	0.257* (0.108)	0.102 (0.105)
Financial incentives for the number of publications at $t-1$		0.029* (0.014)		0.018 (0.021)		0.043* (0.021)		0.044 (0.027)
Promotion requirement at t	−0.162 (0.384)	−0.162 (0.384)	−0.168 (0.315)	−0.168 (0.315)	0.018 (1.853)	−0.511 (0.407)	−0.461 (0.441)	−0.461 (0.441)
Tenure dummy (untenured = 1)	0.133 (0.264)	0.133 (0.264)	0.046 (0.294)	0.046 (0.294)	2.533 (1.767)	0.352 (0.383)	0.589 (0.422)	0.589 (0.422)
Constant	1.225*** (0.185)	0.942** (0.280)	1.638*** (0.318)	1.676*** (0.457)	1.551*** (0.386)	0.766 (0.490)	1.112*** (0.300)	0.680 (0.498)
Observations	340	340	629	629	496	496	521	521
R^2	0.132	0.132	0.022	0.022	0.031	0.031	0.029	0.029
Number of id	45	45	90	90	90	90	173	173

Robust standard errors in parentheses. All models include year dummies.
$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$;
Model significance: F-test; coefficient significance: two-tailed t-tests.

intellectual curiosity and gaining peer recognitions, financial benefits have been an important stimulus in science by noting that financial incentives have influenced scientists to take higher paying positions, start new business based on their research, and choose journals to which they submit their papers (Franzoni et al. 2011; Stephan 2012). The economists' claim has a significant implication for research governance in academia because, unlike the institutional sociology of science which has tended to emphasize peer recognition as the primary incentives in science (Merton 1973), it suggests that the direct incentives based on quantitative performance measurement, which are allocated by administrators, may induce the changed behavior of university scientists.

On one hand, by showing that as financial incentives increased, the average number of SCI papers per researcher also increased from 0.52 in 2004 to 0.73 in 2012 in the studied university, after adjusting for the number of co-authors, this study suggests that the role of financial benefits as a stimulus in science cannot be ignored. On the other hand, however, by demonstrating different responses to specific incentives among varying groups of scientists, this study tells us that the change in research performance should not be interpreted simply as a reaction to monetary gains but as an outcome of complicate interactions among the structure of incentive systems and scientists' position in the stratification in science and their diverse motivations.

These findings suggest that we need to consider not just the amount of incentives but also the structure of incentive systems to elucidate the potential influence of the incentives on research performance and inequality in science. In the next sections, we interpret the influence of the financial incentives based on which we discuss the roles of the incentive structure in cumulative (dis)advantage and the contradiction between intrinsic and extrinsic motivations.

6.2 Non-competitive incentives and inequality in research performance

The findings of this study suggest that the performance-based incentives may reduce the inequality in scientific performance, contrary to the widespread conviction that such differential rewards would exacerbate social inequality problems (Bacache-Beauvallet, 2006; Besley and Ghatak 2003; Boyne and Hood 2010). In the studied university, as financial incentives for publications increased, inequalities among researchers measured by GINI coefficients of the number of publications declined from 0.75 in 2004 to 0.67 in 2012. This *unintentional* result is particularly intriguing because the financial incentives, originally introduced to promote research productivity by adding cash bonuses for high performance in research, helped boost overall performance (the number of publications) and reduce inequality in research performance within the organization at the same time.

The reduced inequality was possible because the performance-based incentives showed distinct effects on researchers with different productivities, resources, and motivation levels. As the incentives for publication increased, lower-ranking researchers improved their publication performances more than did higher-ranking researchers, and many unproductive researchers began to publish papers in SCI-listed journals. As a result, the share of publications by the top 10 percent of researchers shrank, while the share of publications by researchers below the 70th percentile gradually expanded. The proportion of researchers without publications also decreased from 0.46 in 2004 to 0.32 in 2012. The subgroup analyses of fixed-effect model, which controlled for professors' unobserved and time-invariant characteristics such as educational background, gender, and disciplines, also showed that most researchers, except those in the top 10 percent, responded positively to the financial incentives for publications.

What can explain such differences in scientists' responses to the performance-based incentives in the studied university? We speculate that the unique reward structure in the university that awards financial incentives to researchers who publish a paper in any SCI journals, regardless of their rank, may explain the reason for the incentives' stronger effect on lower-ranked researchers when compared with higher-ranked ones. It was not a competition-based winner-take-all game for limited funds but a noncompetitive race for unlimited financial rewards, as any capable researcher had a chance to win the reward and, hence, made efforts to publish papers. As Bohnet and Oberholzer-Gee (2002) noted, such a minimum compensation system was likely to encourage everyone in an organization, including less capable workers, to submit ideas purely to receive the minimum reward. Similarly, the university's financial incentive system seemed to drive less productive researchers rather than top researchers to work harder to publish as a response to the incentives.

In addition, the university offers the incentives based on a simple administrative indicator, i.e., the number of papers. In additionally, unlike some other performance-based incentive systems in which professors are classified into different tiers according to their performance and each tier carries a different financial weight (e.g., Biester and Flink 2015), the same amount of incentives is allocated for each publication. Therefore, the cumulative advantage is less likely to affect the incentive system in the studied university. The theory of cumulative advantage suggests that researchers who had failed to get peer recognitions in their earlier career would have difficult time overcoming disadvantages of peer recognitions and research resources reserved for those with greater record of accomplishment (DiPrete and Eirich 2006; Merton 1973). Therefore, it would be difficult for relatively low-ranking researchers to have strong motivations to raise research performance if the cumulative advantage influenced significantly the allocation of the incentives. Undoubtedly, cumulative advantage may have greater effects on citations and journal impact factors when compared with the simple number of papers. The incentive structure, which considers mainly the number of publications, might, therefore, encourage lower-ranking researchers to participate in the competition for the reward.

On the other hand, the financial incentives for publications did not significantly influence top-ranking researchers. Partly, top-ranking researchers may have already devoted most of their time and efforts to produce sufficient number of papers; thus, additional rewards could not lead to the increased number of publications. In addition, the magnitude of financial incentives for publications may not be big enough to motivate top-ranking researchers to publish additional papers who already have large amounts of support from governments, research institutes, or universities. In contrast, low-ranking researchers, including those without publications, were likely to have restricted resources and, therefore, more likely to respond to external monetary rewards and show interest in publishing more papers. Finally, the motivation theory that emphasizes potential contradiction between intrinsic motivation and external reward systems may also help understand why top-ranked researchers did not respond to the financial incentive for publication, which is discussed in the next section.

6.3 Incentives aligned with intrinsic motivations and quality of research

The findings from the quality of research performance provide additional insights on the incentives for publications, scientists' research practices, and inequalities in research performance. This study found that as financial incentives for the quality of research increased, the average impact factors of all researchers' papers escalated, but the inequality measured by GINI coefficient was not affected. Specially, since 2009, as the maximum reward has risen to $60, 000 and additional $30, 000 incentive has been introduced for publications in journals with impact factors of 20 and higher, the GINI coefficient has risen. Regarding the quality of research performance, the university has developed a complicated incentive system offering a substantial amount of cash rewards for papers in top-ranked journals. As a result, the average impact factors of publications by top 10 percent researchers began to increase after 2009, and multiple fixed-effect model analyses also supported this trend by showing that only top 10 percent researchers have published their papers in journals with significantly higher journal impact factors, as financial incentives for the quality of publications increased.

Notably, the top-ranking researchers did not respond to financial incentives for the number of publications even if they could. To maximize financial benefits, for example, these researchers could have divided their papers and increased the number of papers. However, they responded only to incentives for the quality of research performance. This finding may support the motivation theory by suggesting that external incentives in academia may work as intended only if they are consistent with and supportive of researchers' intrinsic motivations (Andersen and Pellesen 2008; Frey 1997; Frey and Jegen 2001). In academics, top-ranking researchers have been known to be internally motivated and to pursue academic interests, curiosity, or flexibility over monetary compensation and wages (Stern 2004). In our study, therefore, top-ranking researchers who have already published a number of SCI papers were more likely to improve the quality of their publications to satisfy their intrinsic needs, external reputation, and peer recognition and monetary rewards than did middle- or low-ranking researchers.

Since the average journal impact factors of papers produced by less productive researchers were lower when compared with those produced by highly productive researchers, and since most researchers, except top-ranked ones, seemed not to respond to the incentives for the quality of research but the incentives for the number of publications, supporters of meritocracy may question whether such performance-based incentive systems are efficient. They may criticize that many scientists, influenced by performance-based incentives, have produced a greater number of publications with suspicious quality. Given that relatively few papers are cross-cited, a question of whether the increased number of papers deserves valuable resources from the university is critical. Nevertheless, we believe that researchers producing a greater quantity of publications deserve increased resources for two reasons. First, university professors have two primary tasks, education and research. Research helps professors enhance teaching quality by not only introducing the most updated knowledge in the classroom but also increasing students' attention in class when professors present research that they have conducted themselves (Prince et al. 2007). Second, as Figure 4 indicates, the average journal impact factors of papers produced by less productive scientists increased slowly over time. Therefore, we may presume reasonably that with greater number of published papers, researchers who were cumulatively disadvantaged may improve their capacities to compete for better research although further research is needed to prove this hypothesis.

7. Conclusion

Overall, this study suggests that we may be able to reduce the inequality of research performance using a non-competitive minimum reward structure, which effectively helps motivate less productive scientists to advance their research capability and performance. As the sociology of science has noted, once scientists fail to show high productivity in their earlier careers *for any reason*, they are likely to remain second-rate researchers, regardless of their talent. The conventional reward system of science has provided little encouragement for developing the research potential of those in a disadvantageous position owing to cumulative (dis)advantage. In contrast, this study indicates that a well-designed incentive system may strengthen these scientists' motivation for research and reduce inequality in science without sacrificing the quality of research. The results of this therefore suggest that science policymakers and administrators reconsider the value of a non-competitive or less competitive reward structure. Although we do not deny the advantage of the merit-based competitive incentive structure as an efficient way to allocate scarce resources for overall institutional research productivity, we suggest that some resources should be allocated through a non-competitive or less competitive reward structure to enhance research performance of scientists in the disadvantageous position.

More importantly, science policymakers and administrators must reconsider the adoption of a universal performance-incentive system to all scientists at universities or research institutions. Scientists have different levels of motivations and resources, and financial incentives may have different influences on different groups of scientists. The incentive system, therefore, should be tailored to researchers' motivations and resources and applied selectively in consideration of them to be effective. In particular, different incentive structures may need to be devised for top-ranking researchers and other researchers. For example, non-monetary incentives, such as honoring their achievement, might be more effective for top-ranking researchers who are likely to have high levels of intrinsic motivations and large amounts of resources available, whereas monetary incentives might work better for lower-ranking researchers who are likely to have limited resources.

It should be also noted that while this study demonstrated the positive influences of financial incentives in the university studied, the seemingly benign influences can actually harm science. For example, critics have long pointed out the perils of performance measurement, emphasizing the mechanisms through which it affects self-regulation of scientists (Espeland and Sauder 2016; Power 1999; Strathern 2000). The performance-based incentive systems, such as those discussed in this study, tend to rely on simple quantifiable measures of the number of publications or journal impact factors instead of the qualitative evaluations of peer researchers for the reward. Therefore, such incentive systems, according to these critics, may lead researchers at the university to increasingly accept these quantifiable measures as the goal of their research activities. If so, while we witnessed the merit of performance-based reward in increasing research performance and reducing inequality in science, it is possible that such an incentive system would harm both the university and science in general in the long term.

This study has some limitations that should be noted. Although we analyzed a panel data of 450 professors for 9 years, our case study examined a single university in Korea; therefore, readers should be cautious when applying the results and implications of this study in different contexts. In addition, the dynamics of researchers' responses to financial incentives are likely to differ across disciplines, because publication and citation rates vary across disciplines. Owing to the limited sample size, we could not compare scientists' responses to the incentives across disciplines.

We have only limited knowledge of the effects of the performance-based rewards on academic science, mainly because only few empirical studies have been conducted on this important issue. By exploring the influences of financial incentives on inequality of research performance, this study intended to foster further investigation of this increasing trend of new reward systems in academic science.

Notes

1. An interesting exception is Abramo and his colleagues' study on the effects of performance-based research funding to support research performance at Italian universities. Through analyzing the distribution of research performance of university researchers, they speculated that in non-competitive university systems, performance-based research funding to research institutions would put top-researchers in lower-ranking universities in a difficult position to obtain funding when compared with top-researchers in higher-ranking universities (Abramo et al. 2011). However, they paid inadequate attention to the changes in inequality in research performance among individual researchers owing to such performance-based incentive system and failed to conduct empirical analysis to confirm their claim.
2. According to 2017 CWTS Leiden Rankings, based exclusively on bibliographic data from the Web of Science database, the university produced about 5,000 papers from 2012 to 2015 and ranked in the top 200th among 900 major universities worldwide (http://www.leidenranking.com/ranking/2017/list).
3. While the incentive structure was designed and implemented by the administration of the university in a top-down manner, little resistance has been observed from the faculty members mainly because the incentives were considered extra bonuses in addition to salary provided to all professors according to the seniority system.
4. For instance, if there are N co-authors, the paper is counted as $1/(N+2)$. Furthermore, the number of publications is multiplied by two if the professor in our dataset is the first author or corresponding author; thus, the paper is counted as $2/(N+2)$.
5. For the fixed-effect OLS analyses, we calculated the expected values of incentives for the quality of publications based on the product of the proportion of publications in each category at $t-1$ and the amount of cash bonus for the category at t which is described in the following table. Changes in the quality-based incentive between 2004 and 2012 (unit of reward: $100).

Incentive category	2004–08	2009	2010	2011–12
A: IF < 4	1.5	2.5	2.5	2.5
B: 4 ≤ IF < 20	1.5	2.5	2.5	5.0
C: 20 ≤ IF	1.5	2.5	2.5	300
D: *Nature, Science, Cell* (+ *New England Journal of Medicine* and *Lancet* 2009–2012)	100	600	600	600

6. The disciplinary composition across four groups is as follows. The proportion of professors in the field of engineering in four groups ranged from 22 to 29 percent, while the proportion of professors in the natural sciences ranged from 23 to 37 percent. In addition, the proportion of professors in medical sciences ranged from 41 to 54 percent across the groups.
7. For the quality of publications, we used the trends of relative values of impact factors in relation to yearly mean instead of the share of impact factors, because the impact factor of professor i at year t reflected its average rather than sum.
8. Regarding possible random effect model analysis, we conducted Sargan–Hansen test using the command 'xtoverid' in STATA, since the model includes robust standard errors, and the results showed that fixed effect model was more reasonable or preferred over random effect model at 0.05 significance level.
9. In addition, we created four groups based on the quality-adjusted number of publications, which involved the multiplication of a total number of publications and average impact factor for i, t., and conducted multiple fixed-effect OLS analyses between incentives and research performances using those four groups. The signs and levels of significance of variables were consistent with the results presented in Tables 2 and 3 for four groups by the number of publications.
10. We used the financial incentives lagged owing to the delayed adjustment in professors' behaviors. However, in case of promotion requirement, the university applied a grace period for professors to adjust their behaviors before the assessment; thus, we used the promotion requirement without a lag.

Funding

This work was supported by a grant from Kyung Hee University in 2017 (KHU-20171282).

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