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Allocation of Research Resources and Publication Productivity in Japan: A Growth Accounting Approach*

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Abstract

In Japan, as in many developed countries, the government's agencies for science have implemented several reforms to the scientific research system, which has concentrated research resources in the top research universities. However, the growth of research papers has stagnated in Japan during the 2000s. To analyze the reason for this, this paper develops a framework that decomposes the changes in research output. The framework is based on a model of universities and is an application of growth accounting that is widely used in economics. Using the framework, we find that the change in the allocation of research funds between universities had only a small effect on research output. The stagnation in research output during the 2000s was mainly accounted for by the decrease in research time. We also conduct a counterfactual experiment to examine how the research output would increase if the misallocation of research resources were completely removed.

JEL Codes: C43, D24, D61
Keywords: growth accounting; publication productivity; research time; allocation of research funds

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1 Introduction

In Japan, as in many developed countries, the government's agencies for science have implemented several reforms to make the scientific research system more "performance-based." One motive of these reforms is to provide the bulk of research funds and grants to the top research universities. Such reforms brought about two big changes in the systems of the country's universities, especially the national ones. The first change, in the 1990s, was an increase in competitive research funds, which aim to be supplied to top researchers and universities. The second was an institutional change in the national universities in 2004, whereby these universities became independent of the government, and subsidies, which were allocated equally for them, have decreased.

However, the outcome of these policy changes has not necessarily been satisfactory. The left panel in Figure 1 plots the cross-country trend of the number of research papers listed in Web of Science by Thomson Reuters (data in Figure 1 are taken from Saka and Kuwahara, 2013). It shows that the number of research papers in Japan has stagnated in the 2000s, compared with that in other countries or in the previous period. To take the quality of research papers into account, the right panel in Figure 1 plots the number of "top 10% research papers," that is, the top 10% most cited research papers in each research field in each year.[1] This panel also shows stagnation in the publication of research papers in Japan in the 2000s.

Insert Figure 1 here.

Probably, motivated in part by the outcome, some scientists have expressed their opposition to these reforms. For example, Kobayashi (2013), a well-known physicist who won the Nobel Prize in 2008, told Nikkei newspaper, "Too much competition is problematic." "It is difficult to forecast which research will be successful in advance." "Diversity of research projects must be maintained." Toyoda (2012), a biologist and a member of the government's council for Science and Technology policy, wrote in his blog, "Several policies around the period of the institutional change in the national universities, for example, the decrease in the subsidies, an increasing burden on the university management ... and the gap in research funds between the top and the second tier universities must have contributed to stagnation in the number of research papers."

[1] For details on the definition of "top 10% research papers," see Saka and Kuwahara (2012 and 2013).

The purpose of this paper is to evaluate the outcome of this reforms policy. We analyze the reason behind the stagnation in research output in Japan and the extent to which the concentration of research funds in top universities affects this outcome. For the purpose, we construct a framework that decomposes the causes of the stagnation. The framework is based on a model of research activities in universities and is an application of growth accounting in economics literature (see for example, Basu and Fernald, 2002).

Using the framework, we decompose the change in research output of the national universities in Japan during the late 2000s.[2] We find that while the change in the allocation of research funds among these universities had a positive effect on research output, the magnitude is quantitatively small. We further conduct a counterfacual experiment to examine how the research output of the country would increase if the resource misallocation is completely removed. We find that the effect is also quantitatively small.

Our decomposition reveals that despite the increase in research funds for the national universities, measured research productivity has decreased in each university, which results in the stagnation in the growth of research papers. A cause of the decrease in measured research productivity is the decline in research time. Possibly due to several reforms since the late 1990s, faculty members in universities have allocated more time to social service activities and less time to research activities. We show that the decrease in research time accounts for most of the decrease in measured research productivity.

Several papers estimate production functions of research output measured by the number of research papers (Averch, 1987 and Jacob and Lefgren, 2011 at the project-level, Adams and Griliches, 1998, Abigail and Siow, 2003, and Yonetani et al., 2007 at the university-level, Crespi and Geuna, 2006 at the research field-level, and Crespi and Geuna, 2008 at the cross-country-level). Differences between these papers and ours are attributable to those in economics between the regression analysis on production function and growth accounting. While the former estimates parameters using regressions, the latter calibrates them based on the employed model. A characteristic of the latter approach is that the calibrated parameters are unbiased as long as the model and assumptions are correct. It is well known that when regressing the production function the endogeneity bias problem arises, because the independent variables, which consist of the inputs of the production function correlate with the error term, which includes productivity shocks. For example, if the future prospect of a research project is favorable, it is likely that the project

[2]We focus our analysis on national universities, because most of the research papers in Japan originate in national universities. For details, see Section 4.1.

can collect the research resources more easily. Then, the endogeneity bias problem occurs. Our approach can avoid the bias.

Some papers analyze the efficiency of the allocation of research resources between universities or research projects. Using a structural model, Arora et al. (1998) analyze the extent to which the research output would increase if marginal productivies were equalized between research projects. As in their paper, ours is model based, while ours is more analytically tractable, which enable us to derive analytical expression of the decomposition of research output growth. Adams and Clemmons (2009) decomposes the labor productivity growth of research output and measure the extent to which reallocation of research resources between universities contributed the increase or decrease of the productivity growth. Compared with theirs, ours is model-based and decomposes the research output growth, which makes easier to analyze the cause of the stagnation in research output. Hayashi and Tomizawa (2007) analyzes the allocation of funds between universities in Japan. Their scientometrics research shows a scatter plot between research funds and research output over universities. Our paper provides a microfoundation to use the scatter plot and quantify the effect of resource misallocation on research output.

Finally, our study is also closely related with Kanda and Kuwahara (2011), who analyze the declining research time of faculty members in Japan. They find from the micro-level data on researchers' time use that the average research time of a faculty member at a national university has decreased by 20% from 2002 to 2008. Instead, faculty members have spent more time on education, as well as social service activities such as attending the government's councils, transferring technologies to industry, and commercializing research outcomes. Our study uses a growth accounting approach to quantify the impact of the decline in research time.

The remainder of the paper is structured as follows. Section 2 sets up a model of universities. Using the model, in Section 3, we derive a decomposition formula that decomposes the change in research output into several factors such as the productivity effect and allocation effect. Using the decomposition formula, in Section 4, we analyze the publication of research papers at national universities in Japan during the late 2000s. Finally, we present our concluding remarks in Section 5.

2 Model

2.1 Decision problem of a university

Let us consider a model of the government and universities. The government allocates funds (money) to universities. Given the funds I_i allocated to the university, each university (denoted by i) maximizes the research output measured by the number of research papers (or the number of top 10% most cited research papers), y_i. For the purpose, the university buys equipment and goods m_i to be used for research and employs faculty members ℓ_i. Therefore, the university's maximization problem can be stated as follows:

$$\max_{m_i,\ell_i} \quad y_i = a_i f_i(m_i, \ell_i),$$

subject to the budget constraint of the university,

$$pm_i + w_i \ell_i \leq I_i. \tag{1}$$

Here, we assume that the university chooses m_i and ℓ_i under the condition that the price p of equipment and goods and labor cost w_i are exogenously given (we allow the labor cost w_i to vary across universities). a_i is the productivity of the university that can be interpreted as the quality of the institution or its faculty members' abilities, or both. Note that the maximization is a static problem under a single-year budget constraint. Although the decision problem of a university might be dynamic in the real world, as a benchmark, we adopt the static setting.

We assume that the production function of a university is a homogeneous function, i.e.,

$$f_i(nm_i, n\ell_i) = n^{\gamma} f_i(m_i, \ell_i). \tag{2}$$

We assume the diseconomies of scale, i.e., $\gamma < 1$. The assumption is necessary to guarantee that the co-existence of several universities is not inefficient. Otherwise, it becomes efficient for the government to allocate all of the funds to a university whose productivity is the highest.

The first order conditions (FOCs) of the problem are

$$a_i f_{im} = p\lambda_i,\ a_i f_{i\ell} = w_i\lambda_i,\ \lambda_i = \frac{dy_i}{dI_i}, \tag{3}$$

where $f_{im} \equiv \partial f_i(m_i, \ell_i)/\partial m$ and $f_{i\ell} \equiv \partial f_i(m_i, \ell_i)/\partial \ell_i$. λ_i is the Lagrange multiplier of the maximization problem and can be interpreted as the marginal return of research from funds, which measures the increase in research output when the budget of the university increases by an additional unit. Applying Euler's theorem to (2) and substituting the budget constraint (1) and FOCs (3), we obtain

$$\gamma y_i = a_i f_{im} m_i + a_i f_{i\ell} \ell_i = \lambda_i I_i. \tag{4}$$

The equation shows that under (2), the marginal return of research, $\lambda_i = dy_i/dI_i$, is proportional to the average return of research, y_i/I_i, which measures the research output per unit of funds.

2.2 Resource misallocation

The funds allocated to a university, I_i can be linked with the sum of these funds, $I \equiv \sum_i I_i$ as follows (for the derivation, see Appendix A.1):

$$I_i = \frac{y_i}{y} \frac{1}{\tilde{\lambda}_i} I, \tag{5}$$

Note that y is the sum of the research output, that is, $y \equiv \sum_i y_i$, and $\tilde{\lambda}_i$ satisfies

$$\frac{1}{\tilde{\lambda}_i} = \frac{\frac{1}{\lambda_i}}{\sum_j \frac{y_j}{y} \frac{1}{\lambda_j}}. \tag{6}$$

Because λ_i can be interpreted as the return of research from funds at university i, $\tilde{\lambda}_i$ can be interpreted as the relative return of research at university i.

The relative return $\tilde{\lambda}_i$ is a measure of distortion. Suppose the resource allocation that maximizes the research output of the country is

$$\max\ y = \sum_i y_i, \quad \text{subject to } pm_i + w_i\ell_i \leq I_i \text{ for all } i, \text{ and } \sum_i I_i = I.$$

Under the efficient allocation, which maximizes the research output of the country, the return of research is equalized across universities, $\lambda_i = \lambda_j$, and thus the relative return of research $\tilde{\lambda}_i$ is equal to unity for all universities.

To consider the intuition of the result, suppose that the return of research is different across universities, e.g., $\lambda_i < \lambda_j$. Then, by transferring one unit of funds at university i to university j, the research output of the country increases without increasing the resources, which contradicts the efficiency of allocation.

3 Decomposition of Research Output

Using the model introduced in the previous section, this section provides a framework to decompose the causes of the change in research output in Japan. We first explain how the research output of a university is decomposed. Then, we explain how the research output of the country is decomposed. Combining these results, we derive the key equation of decomposition used for measurement.

The research output of a university can be decomposed as follows:

$$\begin{aligned} d\ln y_i =& d\ln a_i + \frac{d\ln y_i}{d\ln m_i} d\ln m_i + \frac{d\ln y_i}{d\ln \ell_i} d\ln \ell_i \\ =& d\ln a_i + \lambda_i \frac{pm_i}{y_i} d\ln m_i + \lambda_i \frac{w_i \ell_i}{y_i} d\ln \ell_i \qquad (7) \\ =& d\ln a_i + \gamma \left(d\ln \frac{y_i}{y} - d\ln \tilde{\lambda}_i + d\ln I \right) \\ & - \gamma \left(\frac{pm_i}{I_i} d\ln p + \frac{w_i \ell_i}{I_i} d\ln w_i \right). \qquad (8) \end{aligned}$$

To derive the result, we use the FOCs (3), Euler's theorem (4), and the following equation obtained by totally differentiating the budget constraint (1):

$$d\ln I_i = \frac{pm_i}{I_i}(d\ln p + d\ln m_i) + \frac{w\ell_i}{I_i}(d\ln w_i + d\ln \ell_i)$$

On the other hand, the research output of the country can be decomposed as follows:

$$\begin{aligned} d\ln y &\approx \sum_i \frac{d\ln\left(\sum_i \exp\{\ln y_i\}\right)}{d\ln y_i} d\ln y_i \\ &= \sum_i \frac{y_i}{y} d\ln y_i. \end{aligned} \tag{9}$$

Combining (8) and (9), we finally obtain

$$\begin{aligned} d\ln y \approx& \sum_i \frac{y_i}{y} d\ln a_i + \gamma d\ln I - \gamma \sum_i \frac{y_i}{y} d\ln \tilde{\lambda}_i \\ &- \gamma \left(\sum_i \frac{y_i}{y} \frac{p_i m_i}{I_i} \right) d\ln p - \gamma \sum_i \frac{y_i}{y} \frac{w_i \ell_i}{I_i} d\ln w_i. \end{aligned} \tag{10}$$

(10) is the key equation of the paper. Note that to derive (10), we use the property that $\sum_i (y_i/y) d\ln(y_i/y)$ becomes approximately zero (see Appendix A.2).

(10) decomposes the growth rate of the research output in a country into several factors in the right-hand side (RHS) of the equation. The first term of the RHS is the weighted average of the productivity growth rate and the second term is the growth rate of total funds invested in the country. The higher these terms, the higher is the growth rate of research output. The third term of the RHS includes $\tilde{\lambda}_i$ and measures the effect of resource misallocation between universities. The fourth and fifth terms measure the price and wage change effects, respectively. The fourth and fifth terms exist because total funds I in the second term are measured in nominal terms. That is, when there is inflation and the price level of goods increases, the equipment and goods a university can purchase decreases if its nominal budget remains unchanged. Similarly, if labor cost increases, the number of faculty members a university can employ decreases. The fourth and fifth terms capture these effects.

All the variables in (10) except for the economies of scale parameter γ can be measured from data.

- Measurement of $d\ln a_i$: Substituting (4) into (7), we measure $d\ln a_i$ by using the following equation:

$$d\ln a_i = d\ln y_i - \gamma \frac{p m_i}{I_i} d\ln m_i - \gamma \frac{w_i \ell_i}{I_i} d\ln \ell_i. \tag{11}$$

- Measurement of $\tilde{\lambda}_{it}$: $\tilde{\lambda}_{it}$ in each year is measured from (5).

- Measurement of $d \ln p$ and $d \ln w_i$: For the former, we use the growth rate of the GDP deflator. For the latter, we use the wage rate for researchers.
- Variables such as y_i/y: In case of y_i/y, we use the average of y_{it-1}/y_{t-1} and y_{it}/y_t.
- The economies of scale parameter γ: γ is not directly measured. Instead of measuring it, we set $\gamma = 0.85$ that is a commonly used value for the extent of decreasing returns in a firm's establishment-level analysis (see Restuccia and Rogerson, 2008).

4 Measurement

4.1 Data

We focus on national universities in our analysis. One reason for doing so is data availability. The other reason is that most of the research papers in Japan originate in national universities. Figure 2 compares research papers at the national level and at national universities. As the figure shows, about 70–90% of the research papers in Japan originate in national universities.

Insert Figure 2 here.

Our sample comprises 63 Japanese national universities that have a science or technology department. Thus, for example, Hitotsubashi University, a national university specializing in social sciences, is not included, because it does not have a science or technology department. We also exclude Sokendai, another national university, because many of its faculty members also belong to other universities such as the University of Tokyo.

We use data from 2005 and 2009, that is, $t-1 = 2005$ and $t = 2009$.[3] For research output (y_i in the model), we use data provided by Saka and Kuwahara (2012), who construct data from Web of Science by Thomson Reuters. We use both the number of research papers and top 10% research papers in the measurement. For the number of faculty members ℓ_i, funds and grants I_i, and labor costs $w_i \ell_i$, we use

[3]More precisely, there is a difference in time intervals between research output data and other data. The research output data count research papers published in 2002–2006 and in 2007–2011, whereas other data are measured at 2005 and 2009. We only adjust the growth rate of research output by multiplying it by 4/5. This is because there is a five-year interval for research output data (between the periods 2002–2006 and 2007–2011), whereas there is a four-year interval for other data (between 2002 and 2006).

data provided by Ishibashi and Tomizawa (2006) and Ishibashi (2011). For the data on price p, we use the GDP deflator.

4.2 Relationship between funds and research output

The model presented in Section 2 predicts that if the resource allocation of funds between universities is efficient, the research output–funds ratio that measures the return of research from funds is also equal between universities. To observe this property in the data, Figure 3 plots the funds and research output of the Japanese national universities (the left panel uses the number of research papers and the right panel uses the number of top 10% research papers for research output).[4] If the allocation were efficient, the scatter plot would be in the straight line crossing the origin. For both $t = 2005$ and $t = 2009$, some dispersion from the straight line is observed. To quantify how big the dispersion is and how it changes over time, in the next sections, we measure (10) to determine the effect of misallocation on research output in Japan.

Insert Figure 3 here.

4.3 Decomposition

Table 1 shows the results of the decomposition using (10). The upper table shows the results when research output y_i is measured by the number of research papers and the lower table shows the results when output is measured by the number of top 10% research papers. Each column calculates each term in (10). For example, $d \ln y_i$ measures the left-hand side (LHS) of (10), the growth rate of paper output; and $d \ln a_i$ measures the first term of the RHS of (10), the weighted average productivity growth rate. We can confirm that in the tables, the $d \ln y_i$ term is equal to the sum of the remaining terms.

Table 1 shows that the increase in funds, $d \ln I$, has a large positive impact on research production. This reflects the fact that in the 2000s, the volume of competitive research funds has substantially increased. However, the growth rate of research output, $d \ln y_i$, falls short of the fund growth. The decrease in growth of average productivity explains the discrepancy. The price effect is positive because of deflation during the period. The wage effect is negative because wage increased during this period.

[4] Hayashi and Tomizawa (2007) plot the same kind of scatter plots.

The allocation effect, $d \ln \tilde{\lambda}_i$, is positive. This is because more funds were allocated to top universities such as the University of Tokyo, where the return of research from funds, y_i/I_i is higher. On the other hand, the magnitude of this effect is small, as compared to the productivity and fund effects.

For each term, a large part of the contribution comes from top universities. For example, in the productivity effect, the contribution of the University of Tokyo is about -2% when y_i is measured by the number of research papers and is about -1% when y_i is measured by the number of top 10% research papers. This is because the size distribution of universities, whose size is measured by, for example, research output, follows a Power law. That is, the distribution has a very unequal fat-tail distribution. As a result, the size of and effect in top universities such as the University of Tokyo becomes far larger than those of other universities.

Insert Table 1 here.

4.4 Magnitude of resource misallocation

In the previous section, we measured the impact of a change in resource allocation on the growth rate of research output. This section analyzes the magnitude of the misallocation. Specifically, we measure how y_t would increase if misallocation *suddenly* and *counterfactually* disappeared in 2009, that is, $\tilde{\lambda}_i = 1$, for all universities. We assume that the productivities a_i, the volume of funds I, the price level p, and wage rates w_i are not changed by the sudden disappearance of misallocation. We further assume that the research output share y_i/y is also unchanged by the disappearance of misallocation. Then, from (10), the increase in research output by the sudden disappearance of misallocation can be calculated by

$$d \ln y = \gamma \sum_i \frac{y_{i,2009}}{y_{2009}} \ln \tilde{\lambda}_{i,2009}, \tag{12}$$

where $y_{i,2009}$ and $\tilde{\lambda}_{i,2009}$ are the research output and distortions, respectively, observed in 2009.

Table 2 calculates (12). The research output increases by 2.3% when y_t is measured by number of research papers and by 8.5% when y_t counts the number of top 10% research papers. These values are small, as compared to the productivity or fund effects in Table 1, taking into account the property that the removal of the misallocation is a one-shot effect, whereas the other factors, especially funds, can be continuously increased.

Our assumption that the research output share y_i/y is not changed by the disappearance of misallocation is somewhat restrictive. This is because if universities are substitutes or complements to one another, the output share of a university changes after the disappearance of misallocation. However, also note that our result in Table 2 holds even if we allow the research output share y_i/y to change after the disappearance of misallocation, if the size of a university y_i/y is uncorrelated with the (log of) distortions at the university, $\ln \tilde{\lambda}_{i,2009}$ (for the proof, see Appendix A.3).

Insert Table 2 here.

4.5 A cause of productivity decline: Shrinking research time

What is the reason for the decline in measured productivity? Some researchers suggest the decrease in research time as a possible cause. Kanda and Kuwahara (2011) report that the annual average research time of a faculty member at a national university has decreased by 20%, from 1,526 hours in 2002 to 1,234 hours in 2008. They find that faculty members have spent more time on education and social service activities, such as attending the government's councils, transferring technologies to industry, and commercializing research outcomes, than on research. Our decomposition framework (10) is flexible enough to deal with the reduction of research time. This section formulates and measures the effect of decreasing research time on research output.

When we incorporate research time into the model in Section 2, only the production function is modified as follows:

$$y_i = a_i f_i(m_i, h\ell_i),$$

where h is the hours a faculty member spends on research. For simplicity, we assume that h is equal across faculty members in different universities. Under the setting, the equation describing the productivity growth of a university (11) is rewritten as

$$d \ln a_i + \gamma \frac{w_i \ell_i}{I_i} d \ln h = d \ln y_i - \gamma \frac{p m_i}{I_i} d \ln m_i - \gamma \frac{w_i \ell_i}{I_i} d \ln \ell_i.$$

Then, the productivity effect in the benchmark decomposition (10) is rewritten as

$$\sum_i \frac{y_i}{y} d \ln a_i + \gamma \left(\sum_i \frac{y_i}{y} \frac{w_i \ell_i}{I_i} \right) d \ln h.$$

The equation shows that the productivity effect in the benchmark decomposition is further divided into the (modified) productivity effect and the research time effect.

Table 3 reports the results that take into account the decrease in research time. The decrease in research time accounts for most of the decrease in the productivity in Table 1. Thus, our result confirms the view suggested by Kanda and Kuwahara (2011) that the decline in research time, possibly induced by several kinds of reforms since the late 1990s, has a substantially negative impact on research activities, especially the publication of research papers.

Insert Table 3 here.

5 Conclusion

In this paper, we analyzed the reasons for the stagnation in research output in Japan during the 2000s. We developed a model of universities, and by using this model, we devised a framework to decompose the change in research output at that time. We applied the framework to the data on research output from the national universities in Japan during the late 2000s. We found that the main reason for the stagnation was the decrease in measured research productivities in each university. The effect of the misallocation of research funds among universities was small. We also found that the decrease in research time of faculty members accounts for the decline in the measured research productivity.

We have to note the limitations of our results. First, we do not take into account "postdocs" and graduate students. Most of them engage in research at top universities, but are low-paid or pay tuition fees by themselves. Their existence should contribute to higer measured productivities and returns of research by funding at top universities. Second, we do not consider the recruiting effect. Top universities sometimes recruit researchers at second-tier universities before their important results are published. For example, Professor Yamanaka, famous for his "iPS cell"research, moved to Kyoto University from Nara Institute of Science and Technology (NAIST) in 2004. Even if his most cited papers were written at Kyoto, the research begun at NAIST. If the research funds allocated selectively, because the measured returns are high, the resource for research might not be given to "future Yamanaka." The recruiting effect should also contribute to higer measured productivities and returns of research by funding at top universities. These are left for future research.

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A Derivations

A.1 Derivation in Section 2.2

I_i can be rewritten as follows:

$$I_i = \frac{\frac{\lambda_i I_i}{\lambda_i}}{\sum_j \frac{\lambda_j I_j}{\lambda_j}} I = \frac{\frac{y_i}{y}\frac{\lambda_i I_i}{y_i}\frac{1}{\lambda_i}}{\sum_j \frac{y_j}{y}\frac{\lambda_j I_j}{y_j}\frac{1}{\lambda_j}} I = \frac{\frac{y_i}{y}\gamma\frac{1}{\lambda_i}}{\sum_j \frac{y_j}{y}\gamma\frac{1}{\lambda_j}} I = \frac{y_i}{y}\frac{\frac{1}{\lambda_i}}{\sum_j \frac{y_j}{y}\frac{1}{\lambda_j}} I.$$

By redefining variables, we obtain (5).

A.2 Derivation in Section 3

Here, we show that $\sum_i (y_i/y) d\ln(y_i/y)$ becomes approximately zero. Define $x_i \equiv y_i/y$. Then, $\sum_i x_i = 1$ and

$$\sum_i \frac{y_i}{y} d\ln\left(\frac{y_i}{y}\right) = \sum_i x_i d\ln x_i \approx \sum_i x_i \frac{dx_i}{x_i} = 1 - 1 = 0.$$

A.3 Derivation in Section 4.4

The proposition can be shown as follows. First, if y_i/y and $\ln\tilde{\lambda}_{i,2009}$ are uncorrelated, $\sum_i (y_i/y - \overline{y_i/y}) \cdot (\ln\tilde{\lambda}_{i,2009} - \overline{\ln\tilde{\lambda}_{i,2009}}) = 0$ (variables with upper bars are the average of original variables). By rewriting the equation, we obtain

$$\sum_i \frac{y_i}{y} \ln\tilde{\lambda}_{i,2009} = \frac{\sum \overline{y_i}}{y} \overline{\ln\tilde{\lambda}_{i,2009}} = \overline{\ln\tilde{\lambda}_{i,2009}}.$$

Then,

$$d\ln y = \gamma \sum_i \frac{y_i}{y} \ln\tilde{\lambda}_{i,2009} = \gamma\overline{\ln\tilde{\lambda}_{i,2009}}. \tag{13}$$

Second, the RHS of (12), ignoring γ, can be interpreted as the weighted average of $\ln \tilde{\lambda}_{i,2009}$.

Because y_i/y and $\ln \tilde{\lambda}_{i,2009}$ are uncorrelated, the (normal) average of $\ln \tilde{\lambda}_{i,2009}$ is equal to the weighted average of $\ln \tilde{\lambda}_{i,2009}$. Therefore, (13) becomes equal to (12).

y_i: Number of research papers

$d \ln y$	$d \ln a_i$	$d \ln I$	$d \ln \tilde{\lambda}_i$	$d \ln p$	$d \ln w_i$
2.0%	−14.5%	16.0%	1.1%	1.3%	−1.9%

y_i: Number of top 10% research papers

$d \ln y$	$d \ln a_i$	$d \ln I$	$d \ln \tilde{\lambda}_i$	$d \ln p$	$d \ln w_i$
11.6%	−5.6%	16.0%	2.4%	1.3%	−2.5%

Table 1: Decomposition of research output growth
Data source: Saka and Kuwahara (2012), Ishibashi and Tomizawa (2006), and Ishibashi (2011).
Notes: The tables show the decomposition of research output in Japan using (10). The upper table shows the results when the number of research papers is used for research output y_i, whereas the lower table shows the results when the number of top 10% research papers is used.

y_i: number of research papers	y_i: number of top 10% research papers
2.3%	8.5%

Table 2: Effects of the disappearance of misallocation on research output
Data source: Saka and Kuwahara (2012), Ishibashi and Tomizawa (2006), and Ishibashi (2011).
Notes: This table calculates how research output would increase if all of the misallocation disappeared. The left column calculates the value for the case where research output is measured by the number of research papers. The right column calculates the value for the case where research output is measured by the number of top 10% research papers.

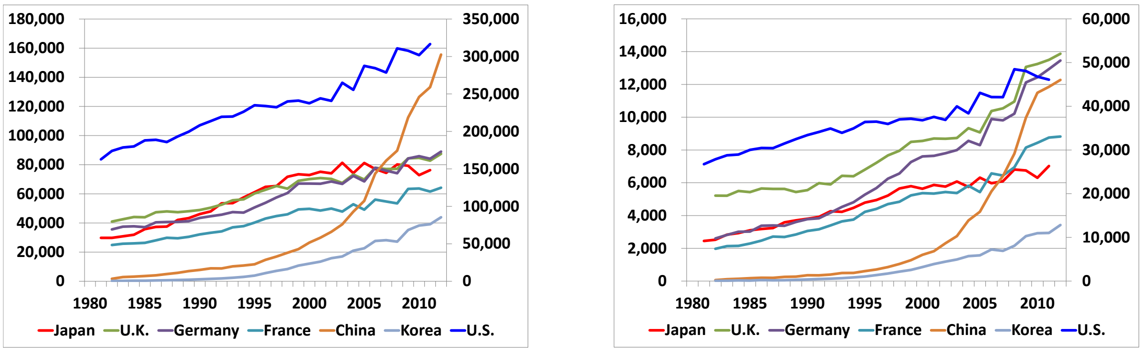
y_i: Number of research papers

$d \ln a_i$ in Table 1	modified $d \ln a_i$	$d \ln h$
−14.5%	−4.7%	−9.8%

y_i: Number of top 10% research papers

$d \ln a_i$ in Table 1	modified $d \ln a_i$	$d \ln h$
−5.6%	3.9%	−9.4%

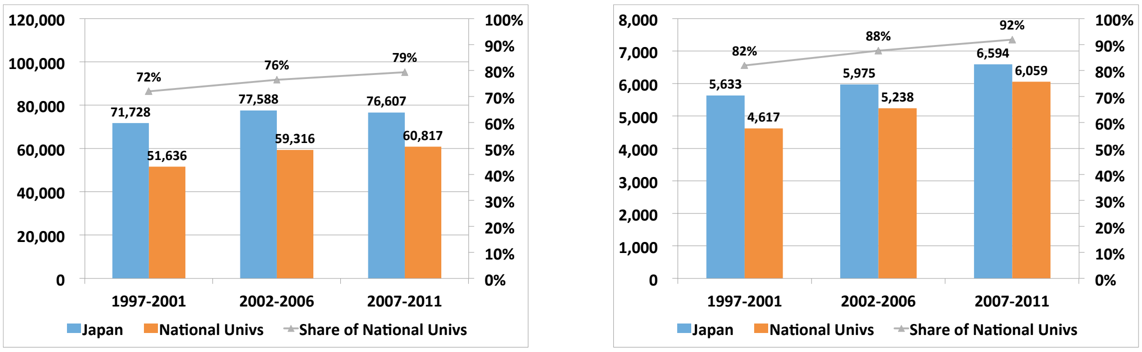
Table 3: Effects of decreasing research time
Data source: Saka and Kuwahara (2012), Ishibashi and Tomizawa (2006), Ishibashi (2011), and Kanda and Kuwahara (2011).
Notes: The tables refine the decomposition in Table 1 to take into account the contribution of the research time of faculty members. Then, $d \ln a_i$ in Table 1 is divided into the (modified) $d \ln a_i$ term and the $d \ln h$ term, the latter capturing the effect of the change in research time on research output. For the growth rate of research time $d \ln h$, we use the average growth rate of research time of a faculty member at a national university from 2002 to 2008. The upper table shows the results when the number of research papers is used for research output y_i, whereas the lower table shows the results when the number of top 10% research papers is used.



(a) Number of research papers

(b) Number of top 10% research papers

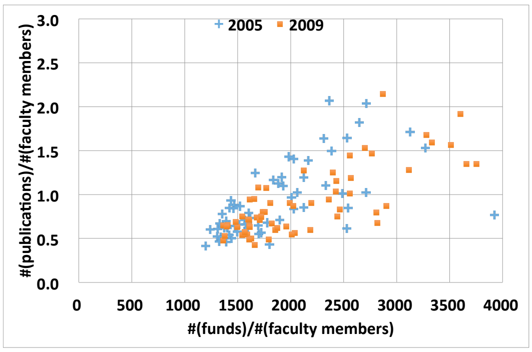
Figure 1: Cross-country trends of the number of research papers
Data source: Saka and Kuwahara (2013). Original data are taken from Web of Science by Thomson Reuters.
Notes: The left panel plots the number of research papers by country, whereas the right panel plots the number of the top 10% most cited research papers by country. For the U.S. in both panels, see the secondary axis.



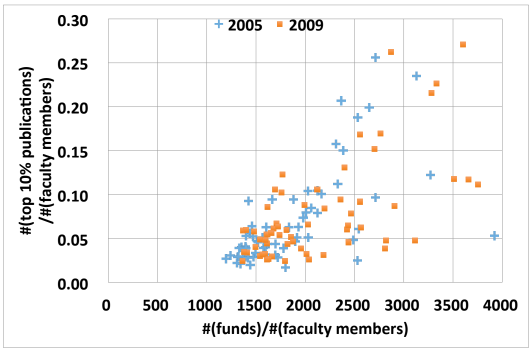
(a) Number of research papers

(b) Number of top 10% research papers

Figure 2: Publication of research papers in Japan at the national level and at national universities
Data source: Saka and Kuwahara (2012 and 2013). Original data are taken from Web of Science by Thomson Reuters.
Notes: The bar graphs in the left panel compare the number of research papers in Japan at the national level with that of national universities for the periods 1997–2001 to 2007–2011. The line graph in the left panel shows the national universities' share of research papers in Japan. The right panel plots these graphs for the number of the top 10% most cited research papers.



(a) Number of research papers



(b) Number of top 10% research papers

Figure 3: Funds–research output relationship
Data source: Saka and Kuwahara (2012), Ishibashi and Tomizawa (2006) and Ishibashi (2011).
Note: The figures show the scatter plots between funds and the number of research papers or the number of top 10% research papers (both per faculty member).