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

Shuhei Aoki †

Department of Economics, Shinshu University

Megumi Kimura ‡

Institute of Innovation Research, Hitotsubashi University

Abstract

In Japan, as in many developed countries, governmental agencies focusing on science have implemented several reforms to the scientific research system, concentrating resources for research towards 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 causes for change in research output. The framework is based on a model of universities and uses techniques in growth accounting. We apply the framework to the data on the national universities in Japan during the late 2000s. We find that the change in the allocation of research funds between universities had only a small effect on research output, measured by the number of research papers. Negative effects on research output were mainly caused by the decrease in research time.

Keywords: growth accounting; publication productivity; research time; allocation of research funds

JEL Codes: C43, D24, D61

I. Introduction

In Japan, as in many developed countries, governmental agencies focusing on science have implemented several reforms to make the scientific research system more "performance-based" in its distribution of resources. One motive of these reforms is to provide the bulk of

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† Address: 3-1-1 Asahi, Matsumoto, Nagano 390-8621, Japan. Phone: +81 (263) 37-2330. Fax: +81 (263) 37-2344. Email: shuhei.aoki@gmail.com.

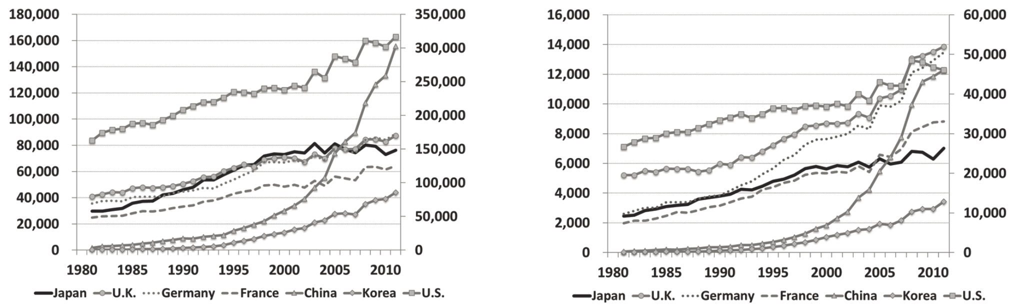
‡ Address: 2-1 Naka, Kunitachi, Tokyo 186-8603, Japan. Phone: +81 (42) 580-8414. Fax: +81 (42) 580-8410. E-mail: kimura@iir.hit-u.ac.jp.

research funds and grants to the top research universities. Such reforms have 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 was aimed 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 from the government, and subsidies, which were allocated evenly, were decreased.

However, the outcome of these policy changes has not been satisfactory. The left panel in Figure 1 plots the cross-country trend of the number of research papers listed on the 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 to that of other countries. 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 every year.[1] This panel also shows stagnation in the number of top 10% research papers in Japan in the 2000s.

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 the 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 former 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

Figure 1. Cross-country trends of the number of research papers



(a) Number of research papers (b) Number of top 10% research papers

Data source: Saka and Kuwahara (2013). Original data taken from the Web of Science by Thomson Reuters.
Note: 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.

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

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."

The purpose of this paper is to evaluate the outcome of this reform policy. Specifically, we analyze the reasons behind the stagnation in research output in Japan and the extent to which the concentration of research funds in the top universities affects this outcome.

For this purpose, we construct a framework that is based on a model of research activities in universities and that decomposes the causes of the stagnation, employing techniques used in the growth accounting literature in economics (see e.g., Basu and Fernald, 2002, Hulten, 2001, and Hulten, 2010). The growth accounting approach is suitable for our purpose in that it is model-based and analytically tractable. The model-based property enables us to quantify the contribution of respective causes. The tractability of the framework gives an analytical expression that allows us to decompose each factor separately.

Using this framework, we decompose the change in research output, measured by the number of research papers or the number of top 10% research papers, of the national universities in Japan during the late 2000s.[2] We find that the change in the allocation of research funds had only a small, albeit positive, quantitative effect on research output. We further conduct a counterfactual experiment to examine whether the research output of the country would increase if the resource misallocation were removed completely. We find that this effect too is quantitatively small.

Our baseline decomposition reveals that measured research productivity has decreased in each university and that it has the most significant negative effect on the number of research papers. A possible cause of the decrease in measured productivity is the change in research time, because in our baseline decomposition, research time is not taken into account. Kanda and Kuwahara (2011) report that the average research time of a faculty member at a national university has decreased by 20% between 2002 and 2008. Instead, according to them, 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. Using the research time data reported in Kanda and Kuwahara (2011), we find that the decrease in measured research productivity is mostly accounted for by the decrease in research time.

Related literature Several papers estimate the production functions of research output, as measured by the number of research papers (Averch, 1987 and Jacob and Lefgren, 2011 at a project-level, Adams and Griliches, 1998, Abigail and Siow, 2003, Yonetani et al., 2013, and Akai et al., 2014 at a university-level, Crespi and Geuna, 2006 at a research field-level, and Crespi and Geuna, 2008 at a cross-country-level). Differences between these papers and ours are similar to the differences between the regression analysis of the production function and

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[2] We focus our analysis on national universities due to data availability. Most of the research papers in Japan originate from national universities. For details, see Section IV–1.

growth accounting in economics. While the former estimates parameters using regressions, the latter calibrates them based on the model employed. 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 can obtain resources for research more easily. Then, the endogeneity bias problem occurs. Our approach can avoid the bias as long as the model and assumptions are correct.[3]

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 productivities were equalized between research projects. As in their paper, we also deploy a model, however, ours is more analytically tractable, which enables us to derive an analytical expression of the decomposition of research output growth. Adams and Clemmons (2009) decompose the growth in labor productivity of research output and measure the extent to which reallocation of research resources between universities contributes to the change in labor productivity. Compared to Adams and Clemmons (2009), our framework is model-based and decomposes the growth in research output, which makes it 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 scatter plots between research funds and research output for universities.[4] Our paper provides a theoretical foundation to use the scatter plots and quantify the effect of resource misallocation on research output.

Outline of the paper Section II sets up a model of universities. Using the model, in Section III, we derive a decomposition formula that decomposes the change in research output into several factors, such as the productivity and allocation effects. Using the decomposition formula, in Section IV, we analyze the publication of research papers by national universities in Japan during the late 2000s. Finally, we present our concluding remarks in Section V.

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[3] For details on the issue discussed here, see the comparison between "econometric approach" and "index numbers approach" in Hulten (2001) and Hulten (2010).

[4] We show similar plots in Figure 3.

II. Model

II–1. Decision problem of a university

Let us consider a model of the government and universities. The government allocates funds (money) to universities. Each university (denoted by i), given the funds I_i allocated to the university, maximizes the research output measured by the number of research papers (or the number of top 10% most cited research papers), y_i. For this 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 given exogenously (we allow the labor cost w_i to vary across universities). a_i is the productivity, or more precisely, total factor productivity (TFP), 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, that is,

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

We assume the diseconomies of scale, that is, $\gamma < 1$. 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 equation (2) and substituting the budget constraint equation (1) and FOC equations (3), we obtain

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

It shows that under equation (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.

II–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 $\tilde{\lambda}_i$ is defined by

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

As 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 (note that from equation (5), $\tilde{\lambda}_i = y_i/I_i/y/I$).

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

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

It can be shown that 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, for example, $\lambda_i < \lambda_j$. Then, by transferring one unit of funds from university i to university j, the research output of the country increases without increasing the overall resources, which contradicts the efficiency of allocation.

III. 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:

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

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

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

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

$$d\ln y = \sum_i \frac{d\ln\left(\sum_i \exp\{\ln y_i\}\right)}{d\ln y_i} d\ln y_i = \sum_i \frac{y_i}{y} d\ln y_i. \qquad (9)$$

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

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

Equation (10) is a key equation of the paper. Note that to derive equation (10), we use the property that $\sum_i (y_i/y) d\ln(y_i/y) = 0$ (see Appendix A–2).

Equation (10) decomposes the growth rate of the research output in a country into several factors on the right-hand side (RHS) of the equation. The first term of the RHS is the weighted average of the growth rate of productivity 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. They exist as total funds I in the second term are measured in nominal terms. The fourth term captures the effect that 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, the fifth term captures the effect that when labor cost increases, the number of faculty members a university can employ decreases.

The decomposition formula equation (10) can be measured in the following way:

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

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

- Measurement of $\tilde{\lambda}_{it}$: $\tilde{\lambda}_{it}$ in each year is measured from equation (5).
- Measurement of $d\ln p$ and $d\ln w_i$: For the former, we use the price index for the intermediate input in the research sector. 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. In the measurement, we set particular values for γ.

IV. Measurement

IV–1. Data

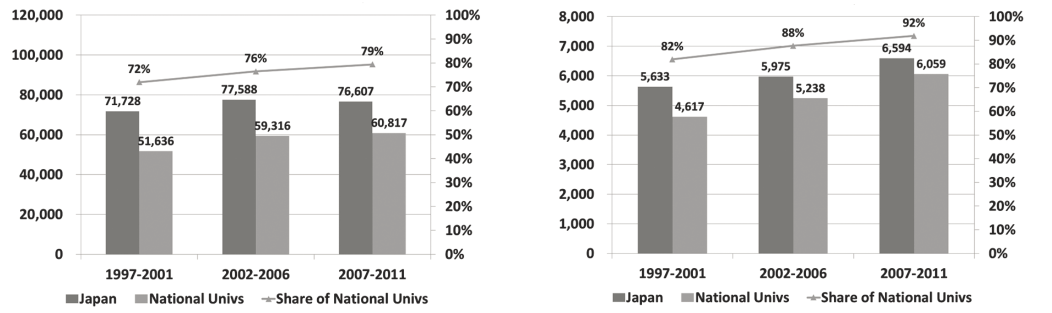
We focus on national universities in our analysis. One reason for doing so is data availability. The other reason is that most of the research papers in Japan originate from national universities. Figure 2 compares research papers at the national level and at national universities. As the figure shows,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

Our sample comprises 63 Japanese national universities that have a science or technology department from 2005 and 2009.[5] 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.

As we note in the previous section, all the variables necessary for the decomposition of equation (10) except for the economies of scale parameter γ, are obtained from the data. Because γ is not directly measured from data, we set $\gamma = 0.85$, which is a commonly used value for the extent of decreasing returns in a firm's establishment-level analysis (see Restuccia and Rogerson, 2008). In Section IV–6, we also try other values for γ for the robustness checks. For research output (y_i in the model), we use both the number of research papers and top 10% research papers in the measurement provided by Saka and Kuwahara (2012), who construct data from the Web of Science by Thomson Reuters. For the number of

[5] More precisely, there is a difference in time intervals between research output data and other data. The research output data counts research papers published from 2002–2006 and from 2007–2011, whereas other data are measured during 2005 and 2009. We only adjust the growth rate of research output by multiplying it with 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).

Figure 2. Publication of research papers in Japan at the national level and at national universities



(a) Number of research papers (b) Number of top 10% research papers

Data source: Saka and Kuwahara (2012 and 2013). Original data taken from the Web of Science by Thomson Reuters.

Note: 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.

faculty members ℓ_i, funds and grants I_i, and labor costs $w_i\ell_i$, we use data provided by Ishibashi and Tomizawa (2006) and Ishibashi (2011). For the data on price p, we use the deflator for the intermediate input in the public research sector, calculated from the JIP Database (Fukao and Miyagawa, 2008).[6]

IV–2. Relationship between funds and research output

The model presented in Section II predicts that if the resource allocation of funds between universities is efficient, the research output–funds ratio, which measures the return of research from funds, is also equal between universities. To observe this property in the data, Figure 3 plots the relationship between the funds and research output of the Japanese national universities at 2005 and 2009 (the left panel uses the number of research papers and the right panel uses the number of top 10% research papers for research output).[7] In the figures, we also draw the best-fit line crossing the origin for each year. If the allocations were efficient, the scatter plot would be in a straight line crossing the origin, in order for the average return of research to be equal across universities. Some dispersion from the straight line is observed. In the next sections, we quantify how the dispersions affect research output.

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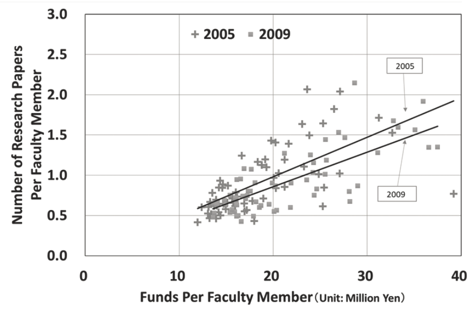
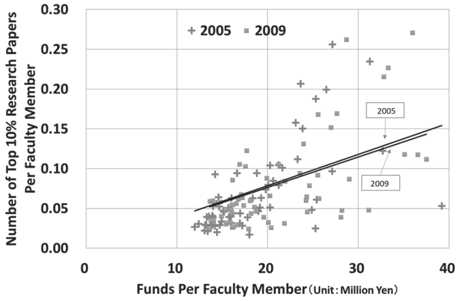
[6] We construct the deflator by dividing "Intermediate input (nominal)" of "99 Research (public)" sector by "Intermediate input (real)" of the same sector in the JIP Database 2014.

[7] Hayashi and Tomizawa (2007) plot similar scatter plots.

Figure 3. Funds–research output relationship



(a) Number of research papers



(b) Number of top 10% research papers

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). The best-fit line crossing the origin is drawn for each year.

IV–3. Decomposition

Table 1 shows the decomposition of research output growth of national universities in Japan between 2005 and 2009 using equation (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 equation (10). For example, $d \ln y_i$ measures the left-hand side (LHS) of equation (10), the growth rate of paper output; and $d \ln a_i$ measures the first term of the

Table 1. Decomposition of research output growth

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%	−11.9%	16.0%	1.1%	−1.4%	−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%	−2.8%	16.0%	2.4%	−1.4%	−2.5%

Data source: Saka and Kuwahara (2012), Ishibashi and Tomizawa (2006), and Ishibashi (2011).

Note: The tables show the decomposition of research output growth of national universities in Japan between 2005 and 2009 using equation (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.

RHS of equation (10), the weighted average growth rate of productivity. 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 and the wage effect are both negative because price for research goods and wage increased during this period.

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 -1.5% when y_i is measured by the number of research papers and is about -0.5% 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.

IV–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 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. Then, from equation (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. Note that the above equation is a first-order approximation. Therefore, when the magnitude of the misallocation is large, the figure measured by equation (12) deviates from the true value.

Table 2 calculates equation (12). The research output increases by 2.3% when y is measured by number of research papers and by 8.5% when y 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-time effect.

Table 2. Effects of the disappearance of misallocation on research output

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

Data source: Saka and Kuwahara (2012), Ishibashi and Tomizawa (2006), and Ishibashi (2011).
Note: This table calculates how research output would increase if misallocation was removed completely in 2009. 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.

IV–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 councils, transferring technologies to industry, and commercializing research outcomes, than on research. Our baseline decomposition in Section IV-3 ignores changes in research time. This section analyzes and measures how decreasing research time accounts for the decline in measured productivity.

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

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

where h represents 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

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

Then, the productivity effect in the benchmark decomposition equation (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.

Table 3. Effects of decreasing research time

y_i: Number of research papers

$d \ln a_i$ in Table 1	modified $d \ln a_i$	$d \ln h$
−11.9%	−2.1%	−9.8%

y_i: Number of top 10% research papers

$d \ln a_i$ in Table 1	modified $d \ln a_i$	$d \ln h$
−2.8%	6.6%	−9.4%

Data source: Saka and Kuwahara (2012), Ishibashi and Tomizawa (2006), Ishibashi (2011), and Kanda and Kuwahara (2011).

Note: 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.

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 had a substantially negative impact on research activities, especially the publication of research papers.

IV–6. Robustness checks: different γs

The economy of scale parameter γ is not measured but is set to 0.85. For the robustness checks, we set different values to γ and see how the results obtained above are changed. Table 4 shows the results. We find that the results obtained above are essentially unchanged.

Table 4. Robustness checks for the economy of scale parameter γ

y_i: Number of research papers

$\gamma = 0.75$

$d \ln y$	modified $d \ln a_i$	$d \ln h$	$d \ln I$	$d \ln \tilde{\lambda}_i$	$d \ln p$	$d \ln w_i$
2.0%	−1.6%	−8.7%	14.1%	1.0%	−1.2%	−1.6%

$\gamma = 0.95$

$d \ln y$	modified $d \ln a_i$	$d \ln h$	$d \ln I$	$d \ln \tilde{\lambda}_i$	$d \ln p$	$d \ln w_i$
2.0%	−2.6%	−11.0%	17.9%	1.3%	−1.5%	−2.1%

y_i: Number of top 10% research papers

$\gamma = 0.75$

$d \ln y$	modified $d \ln a_i$	$d \ln h$	$d \ln I$	$d \ln \tilde{\lambda}_i$	$d \ln p$	$d \ln w_i$
11.6%	7.2%	−8.3%	14.1%	2.1%	−1.3%	−2.2%

$\gamma = 0.95$

$d \ln y$	modified $d \ln a_i$	$d \ln h$	$d \ln I$	$d \ln \tilde{\lambda}_i$	$d \ln p$	$d \ln w_i$
11.6%	6.0%	−10.5%	17.9%	2.6%	−1.6%	−2.8%

Data source: Saka and Kuwahara (2012), Ishibashi and Tomizawa (2006), Ishibashi (2011), and Kanda and Kuwahara (2011).

Note: The tables show the decompositions when different values for the economy of scale parameter γ are set. They combine decompositions in Tables 1 and 3. The upper tables show the results when the number of research papers is used for research output y_i, whereas the lower tables show the results when the number of top 10% research papers is used.

V. 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. We applied the framework to the data on research output of the national universities in Japan during the late 2000s. We found that during the period, the decrease in measured research productivities in universities affect research output most significantly. The effect of the misallocation of research funds among universities was small. We also found that the decrease in research time of faculty members, possibly induced by several kinds of reforms since the late 1990s, accounts for the decline in 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 either lowly paid or pay tuition fees by themselves. Their existence should contribute to higher measured productivities and returns of research 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 Shinya Yamanaka, a 2012 Nobel Laureate in Physiology or Medicine 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 began at NAIST. The recruiting effect should also contribute to higher measured productivities and returns of research at top universities. If the research funds were allocated selectively, based on the measured productivities, the resource for research might not be given to “future Yamanaka.” These are topics for future research.

References

Abigail, Payne A. and Aloysius Siow (2003) “Does Federal Research Funding Increase University Research Output?” *The B.E. Journal of Economic Analysis and Policy*, Vol. 3, No. 1, pp. 1–24.

Adams, James D. and J. Roger Clemmons (2009) “The Growing Allocative Inefficiency of the U.S. Higher Education Sector,” in *Science and Engineering Careers in the United States: An Analysis of Markets and Employment*: NBER, pp. 349–382.

Adams, James D. and Zvi Griliches (1998) “Research Productivity in a System of Universities,” *Annales d’Economie et de Statistique*, No. 49–50, pp. 127–162.

Akai, Nobuo, Wataru Senoh, and Kensuke Mizuta (2014) “On the Fund Allocation and Governance of Government Expenditures and Education in Japan (in Japanese),” Discussion papers 14-J-009, RIETI, Japan.

Arora, Ashish, Paul David, and Alfonso Gambardella (1998) “Reputation and Competence in Publicly Funded Science: Estimating the Effects on Research Group Productivity,” *Annales d’Economie et de Statistique*, No. 49–50, pp. 163–198.

Averch, Harvey A. (1987) “Measuring the Cost-Efficiency of Basic Research Investment: Input-Output Approaches,” *Journal of Policy Analysis and Management*, Vol. 6, No. 3, pp. 342–361.

Basu, Susanto and John G. Fernald (2002) “Aggregate Productivity and Aggregate Technology,” *European Economic Review*, Vol. 46, No. 6, pp. 963–991.

Crespi, Gustavo A. and Aldo Geuna (2008) “An Empirical Study of Scientific Production: A Cross Country Analysis, 1981-2002,” *Research Policy*, Vol. 37, No. 4, pp. 565–579.

Crespi, Gustavo and Aldo Geuna (2006) “The Productivity of UK Universities,” SPRU Working Paper Series, University of Sussex.

Fukao, Kyoji and Tsutomu Miyagawa eds. (2008) *Productivity and Japan’s Economic Growth: Industry–Level and Firm–Level Studies Based on the JIP Database (in Japanese)*: University of Tokyo Press.

Hayashi, Takayuki and Hiroyuki Tomizawa (2007) “Transition of Research Performance and Research Structure in Japan (in Japanese),” *Research on Academic Degrees and*

University Evaluation, Vol. 5. National Institution for Academic Degrees and University Evaluation.

Hulten, Charles R. (2001) "Total Factor Productivity: A Short Biography," in Hulten, Charles R., Edwin R. Dean, and Michael J. Harper Eds. *New Developments in Productivity Analysis*, Vol. 63 of Studies in Income and Wealth: NBER, pp. 1–47.

——— (2010) "Chapter 23 - Growth Accounting," in Hall, Bronwyn H. and Nathan Rosenberg eds. *Handbook of the Economics of Innovation, Volume 2*, Vol. 2 of Handbook of the Economics of Innovation: North-Holland, pp. 987–1031.

Ishibashi, Eiji (2011) "Report of the Survey of Scientific, Technological and Academic Activities in the Universities (in Japanese)," Research Report, NISTEP, MEXT, Japan.

Ishibashi, Eiji and Hiroyuki Tomizawa (2006) "Report on the Survey of Scientific, Technological and Academic Activities in the Universities (in Japanese)," Research Report, NISTEP, MEXT, Japan.

Jacob, Brian A. and Lars Lefgren (2011) "The Impact of Research Grant Funding on Scientific Productivity," *Journal of Public Economics*, Vol. 95, No. 9–10, pp. 1168–1177.

Kanda, Yumiko and Terutaka Kuwahara (2011) "Shrinking Research Time for University Faculty Members: Comparison of 2002 and 2008 in the 'Survey on Full-Time Equivalents at Universities' (in Japanese)," Discussion Paper No. 80, NISTEP, MEXT, Japan.

Kobayashi, Makoto (2013) "Concerns about the Excessive Emphasis on Competitive Funds (in Japanese)," Nikkei Newspaper, 01/08/2013, Japan.

Restuccia, Diego and Richard Rogerson (2008) "Policy Distortions and Aggregate Productivity with Heterogeneous Establishments," *Review of Economic Dynamics*, Vol. 11, No. 4, pp. 707–720.

Saka, Ayaka and Terutaka Kuwahara (2012) "Benchmarking Research & Development Capacity of Japanese Universities 2011 - Improving Universities Research Activities by Identifying Characteristics and Strength of Each University - (in Japanese)," University Research Benchmarking Series, NISTEP, MEXT, Japan.

——— (2013) "Benchmarking Scientific Research 2012 - Bibliometric Analysis on Dynamic Alteration of Research Activity in the World and Japan - (in Japanese)," University Research Benchmarking Series, NISTEP, MEXT, Japan.

Toyoda, Nagayasu (2012) "Too Abnormal Curve of the Number of Research Papers in Japan (inJapanese),"http://blog.goo.ne.jp/toyodang/e/26f372a069cbd77537e4086b0e56d347, 27/06/2012.

Yonetani, Yutaka, Kenta Ikeuchi, and Terutaka Kuwahara (2013) "An Analysis on the Relationship between Input and Output in the Production of Articles in Universities – An Approach using Web of Science and Survey of R&D (in Japanese)," Research Report, NISTEP, MEXT, Japan.

A. Derivations

A–1. Derivation in Section II–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 equation (5).

A–2. Derivation in Section III

Here, we show that $\sum_i (y_i/y) d\ln(y_i/y) = 0$. Define $x_i \equiv y_i/y$. Then, $\sum_i x_i = 1$ and

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