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An international comparison of relative contributions to academic productivity

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This paper presents a methodology for measuring the improvements in efficiency and adjustments in the scale of R&D (Research & Development) activities. For this purpose, this study decomposes academic productivity growth into components attributable to (1) world academic frontier change, (2) R&D efficiency change, (3) human capital accumulation, and (4) capital accumulation. The world academic frontier at each point in time is constructed using data envelopment analysis (DEA). This study calculates each of the above four components of academic productivity for 27 countries over 1990–2003, and finds that the components which contribute to academic productivity growth vary with the different countries' characteristics and development stages. Human capital has more weight in terms of the quantity of academic research, and capital accumulation plays a more important role in the citation impact of academic research.

Introduction

Over the past twenty years, there has been a dramatic change in world output of academic publications. While the growth in the U.S. share of world academic publications flattened in the 1990s, the growth of publication share in the European Union and markedly in the developing East Asian economies continued to increase [MAY, 1997; OECD, 2008]. The share of citations as well as that of top 1% highly cited articles show a similar pattern to publication outputs among countries [NATIONAL SCIENCE BOARD, 2008]. These changes appear to conceal the improved academic capacity of Asian countries, thereby narrowing the gap in scientific outputs between the U.S. and the emerging economies.

While investments in R&D and in human resources are tended to be considered two major inputs to enhance national scientific capacity, seldom have studies investigated whether these investments are used efficiently and to what extent the various investments contribute to the changes in academic productivity. Given the continued growth of R&D spending and numbers of researchers, governments around the world

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have placed more emphasis on research productivity and accountability. This study will attempt to identify whether the growth in academic productivity is relatively attributed to the efficient use of resources or to the increase in R&D inputs at the national level. Specifically, this paper presents a nonparametric method, Malmquist Data Envelopment Analysis (DEA), to decompose the sources of growth in academic productivity. We start with a more general discussion about the main approaches to measure productivity.

A simple method is to calculate the ratio of output/input, assuming all other input factors are fixed. Although the simple ratio of output/input is often used for international comparison of research productivity [EUROPEAN COMMISSION, 2003; KING, 2004], it has limited value to inform the sources of productivity growth. First of all, the output/input ratio is generally referred to a single-input single-output relation, while scientific production tends to involve in multiple inputs and multiple outputs, where the relationship is rather complex and reciprocal. Moreover, the output/input ratio appears to assume that there is no inefficiency in the production process and that the productivity growth is purely attributed to technical advance. In real world, this assumption seems to ignore the effect of efficiency change on productivity improvements.

The production function approach and the production frontier approach are the more sophisticated approaches to measure academic productivity. Bonaccorsi & Dario (2004) present an introduction of the two approaches applied in S&T systems, the underlying assumptions, and the limitations. Both approaches allow one to measure productivity by taking into account all inputs and outputs. Nevertheless, there is a fundamental difference in measuring performance of the observations. In the production function approach, the relationship between inputs and outputs is constructed as a functional form, where the coefficients of regression equation are estimated to reflect the average tendency of the observations. On the other hand, the production frontier approach identifies at least one point of best performance as the "frontier" and measures the distance between each observation and the frontier. Therefore, the performance measure of production frontier approach is based on the individual observations relative to the frontier.

While the production function approach has been substantively used in measuring the contribution of R&D investments to productivity growth [ADAMS, 1990; GRILICHES, 1979] as well as to scientific production [ADAMS & GRILICHES, 2000; CRESPI & GEUNA, 2008], it has some restrictive assumptions in measuring academic productivity. First of all, it needs to specify a functional form of the production function and a distributional form of the inefficiency term. Therefore, this method is better applied to well-structured production processes [BONACCORSI & DARIO, 2006]. Nevertheless, the processes of scientific production is rather complex. The relationships between inputs and outputs tend to be non-linear, non-deterministic, and uncertain. Measuring academic productivity by specifying a functional form may lead to biased results.

Moreover, the explanatory variables in econometric approaches are assumed to be mutually independent, while the R&D investments, such as the R&D expenditure and researchers, are linearly dependent. The multi-collinearity problem among explanatory variables of academic productivity fails to meet the assumption of econometric technique.

Compared with the production function approach, the production frontier approach appears to have several advantages in its application to science systems. The Stochastic Frontier Analysis (SFA) and the Data Envelopment Analysis (DEA) are two major approaches to measure efficiency. While the former applies the econometric technique, the latter applies a linear programming technique, which requires no specification of the functional form for the production function and thereby avoids the abovementioned limitation of the production function approach. Furthermore, the frontier line is constructed by a linear combination of the observed data points with efficiency, which could be served as references for best practice. The input slack is reported as inefficiency in DEA approach, therefore, there is no need to specify a distributional form for inefficiency term or to assume that the efficiency among observations is fixed.

DEA was first introduced by CHARNES & AL. [1978], who generalised the FARRELL [1957] single-output/input technical-efficiency measure to multiple-output/multiple-input case [CHARNES & AL., 1994]. Since then, this approach has been widely applied to measure efficiency in various contexts, such as health care, banking, education, and so on. A variety of models based on DEA approach have also been developed. In recent year, several studies have applied DEA-based methods to measure research efficiency and productivity in S&T systems. The units of analysis have been at a programme level [SOARES DE MELLO & AL., 2006], at a department level (Korhonen, et al., 2001), at a university or research institution level [ABRAMO & AL., 2008; BONACCORSI & DARIO, 2003; BONACCORSI & AL., 2006; THURSBY & KEMP, 2002; THURSBY & THURSBY, 2002; WORTHINGTON & LEE, 2008], and at a country level [MENG & AL., 2006; ROUSSEAU & ROUSSEAU, 1997, 1998; SHARMA & THOMAS, 2008; WANG & HUANG, 2007]. These studies suggest that the DEA-type approaches appear to emerge as an analytical tool for investigating the complex relationship between inputs and outputs in S&T systems.

In the literature related to the measurement of research efficiency, previous studies have compared the levels of relatively technical-efficiency among countries in a given time point [ROUSSEAU & ROUSSEAU, 1997, 1998], but most of them did not analyse the productivity changes over time. Comparing productivity over time tends to involve in an additional source of productivity change, technical change, in additional to efficiency change. Recently, SHELTON [2008] investigates the major inputs in predicting academic outputs across countries by multiple regression analysis. One of the results shows that research investments are much more important than the number of researchers. The study does not take technical changes into consideration.

This study focuses on the academic productivity changes at a national level by adopting the Malmquist DEA approach to decompose the sources of growth in academic production. Malmquist productivity index was first introduced by CAVES & AL. [1982] to measure productivity difference. FÄRE & AL. [1994] develop this index using a nonparametric method to decompose productivity into changes in efficiency and changes in technology. Therefore, the Malmquist DEA approach has the advantages of nonparametric method, which is no need to specify a functional form and allows for inefficiency performance. Meanwhile, this approach allows for identifying mutually exclusive and exhaustive sources of changes in productivity. The concept and model of the Malmquist DEA approach are further discussed in the next section.

This study decomposes the growth of academic productivity into four components that are each attributable to one of the following: (1) world academic frontier change, (2) R&D efficiency change, (3) human capital accumulation, and (4) capital accumulation. The world academic frontier at each point in time is constructed using data envelopment analysis (DEA), which is a deterministic and nonparametric method, and efficiency is measured as the distance from the frontier. These data-driven methods do not require the specification of any particular functional form for the academic production. We calculate each of the above four components of academic productivity for 27 countries, all of which play an important role in published outputs, over the 1990–2003 period. These methods help to fulfill one important objective of this paper, which is to develop a distinct link between R&D activity and academic productivity by decomposing the growth of academic productivity. The result shows that the components which contribute to academic productivity growth vary with each country's characteristics and development stages. Each factor has a different impact on academic research. More weight is attached to human capital in terms of the quantity of academic research, and capital accumulation plays a more important role in the citation impact of academic research.

Methods of assessment of academic productivity

This study uses DEA approach with the conceptual decomposition to measure the growth in academic productivity at national level. The unit of analysis, named Decision Making Unit (DMU), should be homogeneous entities that use the same inputs to produce the same outputs. When applying this method in the context of S&T system, we regard academic research as a production process and each country as a DMU that engages in academic activities and transforms the same input into the same output. Furthermore, each DMU should have equal access to input. In academic production process, however, several environmental factors may influence the efficiency and productivity of a DMU. These factors, such as language proficiency and scientists' preference to publish, are generally not under the control of the decision-makers of the

DMUs. DEA approach also allows for considering the environmental factors. Nevertheless, this study does not further examine this issue.

DEA approach produces a revealed best-practice production frontier, which is formed by the DMUs that use their inputs most efficiently to generate outputs. All other DMUs beneath the frontier are considered technically inefficient, and the distance of each DMU from the frontier is computed as the efficiency score. Combining the technique of measuring efficiency with that of measuring productivity change over time, the DEA-based Malmquist productivity index allows the sources of productivity growth to be decomposed into technical changes and efficiency changes.

This study follows the framework set by KUMAR AND RUSSELL [2002] and decomposes the growth of academic productivity into four components: (1) world academic frontier change, (2) R&D efficiency change, (3) human capital accumulation, and (4) capital accumulation. The first component reflects shifts in the world academic frontier. Here the world is defined as the countries in our sample. Since the publication share of the total sample countries is over ninety percent, the sample countries should be representative of the world scientific production. A downward shift of the academic frontier could be interpreted as the competition among these countries in scientific capabilities to produce less publication share in a given input quantity over time. The second component, R&D efficiency change, reflects movements toward the frontier. It shows how much the observed production of a country is getting closer (or catching up) to the academic frontier. The third and the fourth components reflect the movement along the frontier in terms of the inputs to human capital and to capital accumulation, respectively.

This study deals with one aggregated academic output and two aggregated inputs. Let (P_{it}, L_{it}, K_{it}), t = 1,2..T, i = 1, …N, represent T observations for these three variables for each of the i countries. This paper regards academic output as a production process and each country as a decision-making unit (DMU) that engages in academic activities. The piecewise linear input requirement set under variable returns to scale for all DMUs combined in the world in period t can be expressed as:

$$T_t = \left\{ \langle P,L,K \rangle \in R_+^3 \,\middle|\, P \le \sum_i z^i P_t^i, L \ge \sum_i z^i L_t^i, K \ge \sum_i z^i K_t^i, \sum_i z_i = 1, z^i \ge 0 \,\forall i \right\} \quad (1)$$

In this construction each observation is interpreted as a unit operation of a linear process; z_i represents the level of operation of that process, and every point in the frontier set is a linear combination of observed one output (P) and two input manpower (L) and capital accumulation (K) or a point dominated by a linear combination of observed points.

This simple hypothetical frontiers for two periods, say a base period t and a current period t+1, are drawn in Figure 1. The frontier is the curve by the linear combination of each efficient unit, indicating the efficient science system. The two points, (K_t,P_t) and

(K_{t+1},P_{t+1}), represent the observed values of input and output. The potential outputs per efficient unit of capital accumulation in the two periods are given by $\overline{P}_t(K_t)$ and $\overline{P}_{t+1}(K_{t+1})$

$$\frac{P_{t+1}}{P_t} = \frac{e_{t+1} \times \overline{P}_{t+1}(K_{t+1})}{e_t \times \overline{P}_t(K_t)} , \qquad (2)$$

where e_{t+1} and e_t are the values of the efficiency indexes in the two period:

By multiplying the numerator and denominator of (2) by $\overline{P}_{t+1}(K_t)$ the potential output at the base-period capital accumulation using the current-period frontier, we obtain

$$\frac{P_{t+1}}{P_t} = \frac{e_{t+1}}{e_t} \times \frac{\overline{P}_{t+1}(K_{t+1})}{\overline{P}_{t+1}(K_t)} \times \frac{\overline{P}_{t+1}(K_{t+1})}{\overline{P}_t(K_t)} . \qquad (3)$$

We are able to decompose the identity of the relative change in the output in the two periods into three components. The first term on the right reflects the change in R&D efficiency, which can be attributable to pure R&D efficiency change and scale efficiency change—that is the change in the distance from the frontier. The second term represents the shift in the world academic frontier. And the third term shows the effect of the change in the capital accumulation (movement along the frontier).

Now the shift in Eq. (3) is expressed in Figure 1. It assumes that the input and output in the T period is point A and the value of input and output are (K_t, P_t).

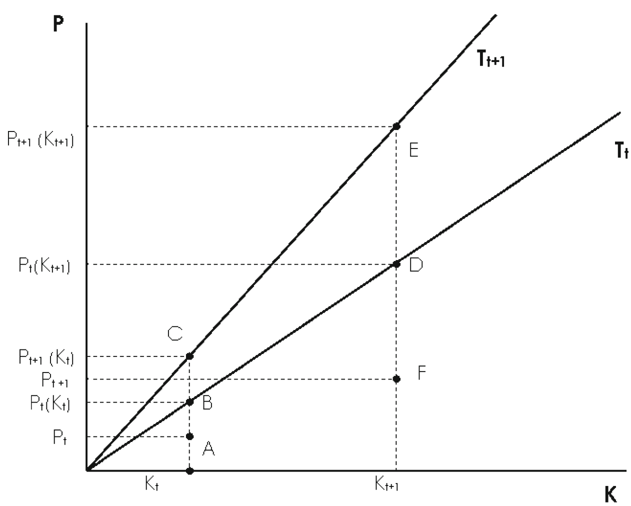

Figure 1. Illustrate of R&D efficiency, capital accumulation, frontier and academic productivity changes

The input and output in the T+1 period is point F, and the value of input and output are (K_{t+1}, P_{t+1}). The efficiency of T period $(P_t/P_t(K_t)$ is e_t, and, the efficiency of T+1 period

$\{P_{t+1}/P_{t+1}(K_{t+1})\}$ is e_{t+1}. To measure the shift of world academic frontier, it is able to set K_t as a base value, and shifts from point B to point C ($P_{t+1}(K_t)/P_t(K_t)$), or to set K_{t+1} as a base value, and shifts from point D to point E ($P_{t+1}(K_{t+1})/P_t(K_{t+1})$). When measuring the impact of R&D input, it's able to shift from point B to point D, taking frontier T as base, or, shift from point C to point E, taking frontier T+1 as base.

Since the academic frontier-change and R&D investment components may be path dependent, avoiding choosing the benchmark arbitrariness, the measure used here is based on a geometric average of these changes relative to period t and t+1 benchmark. This study follows both paths by adopting the "Fisher ideal" decomposition to show the relative changes in the academic productivity. The decomposition is based on geometric averages of the three measures of the effects of academic frontier change, human capital, and capital accumulation, to derive the following equation:

$$\frac{P_{t+1}}{P_t} = \frac{e_{t+1}}{e_t} * \left(\frac{\overline{P}_{t+1}(L_t, K_t)}{\overline{P}_t(L_t, K_t)} * \frac{\overline{P}_{t+1}(L_t, K_{t+1})}{\overline{P}_t(L_t, K_{t+1})} * \frac{\overline{P}_{t+1}(L_{t+1}, K_t)}{\overline{P}_t(L_{t+1}, K_t)} * \frac{\overline{P}_{t+1}(L_{t+1}, K_{t+1})}{\overline{P}_t(L_{t+1}, K_{t+1})} \right)^{1/4}$$

$$* \left(\frac{\overline{P}_t(L_{t+1}, K_t)}{\overline{P}_t(L_t, K_t)} * \frac{\overline{P}_t(L_{t+1}, K_{t+1})}{\overline{P}_t(L_t, K_{t+1})} * \frac{\overline{P}_{t+1}(L_{t+1}, K_t)}{\overline{P}_{t+1}(L_t, K_t)} * \frac{\overline{P}_{t+1}(L_{t+1}, K_{t+1})}{\overline{P}_{t+1}(L_t, K_{t+1})} \right)^{1/4}$$

$$* \left(\frac{\overline{P}_t(L_{t+1}, K_{t+1})}{\overline{P}_t(L_{t+1}, K_t)} * \frac{\overline{P}_t(L_t, K_{t+1})}{\overline{P}_t(L_t, K_t)} * \frac{\overline{P}_{t+1}(L_{t+1}, K_{t+1})}{\overline{P}_{t+1}(L_{t+1}, K_t)} * \frac{\overline{P}_{t+1}(L_t, K_{t+1})}{\overline{P}_{t+1}(L_t, K_t)} \right)^{1/4}$$

$$= \mathrm{EFF} \times \mathrm{TECH} \times \mathrm{Human} \times \mathrm{R\&D\_inv}. \quad (4)$$

Data

A total of 27 countries form the sample used in this study. The quantitative inputs for academic research are mainly manpower and physical resources. Manpower is measured in terms of full-time equivalent researchers. Physical resources are measured in terms of gross domestic expenditure on R&D in USD based on purchasing power parities (PPP). The researchers are indicated as human capital accumulation whereas the R&D expenditures are indicated as capital accumulation in the paper. These input data are released by OECD sources.

The publication of journal papers is the most common indicator of academic research output. The bibliometric data used in compiling the National Science Indicator (NSI) is applied. Those papers published in the Science Citation Index (SCI) and Social Science Citation Index (SSCI) are contained in the NSI, which divides papers into 24 disciplines. The indicators of academic productivity employed in this study comprise the two shares described below. (1) The publication share (PS_{all}), which is described as a basic measure of scientific productivity or output. Let PS_f represent a country's share among the world's output of publications in a given field f, f =1 to F. PS_{all}, which equals the average of PS_f in every field, and denotes a country's total share of the world's publications. (2) The citation share (CS_{all}), which records the citation times of each country's international journal papers in the SCI or SSCI. Citations are a very good measure of the quality of scientific work for use in sociological studies [COLE, 1989]. Therefore it could be an indicator of the visibility and influence of a country's published output. This study assumes that the large majority of the citations reflect genuine acknowledgements to relevant cited literature, and the errors and biases in the citing process could be at least reduced to an acceptable level when the statistics relate to high aggregate levels such as countries, fields of research. Hence, when conducting country level analysis, it is reasonable to assume that these citations will represent a valid proxy, and be a suitable measure of influence and visibility of science. This is an indicator of the visibility and influence of a country's published output. Let CS_f represent a country's share among the world's citation in a given field f, f = 1 to F. CS_{all}, which equals the average of CS_f in every field, denotes a country's total share of the world's paper citation.

Since a certain length of time is required before academic research is completed and papers are published, a time lag should be taken into account in conducting a DEA evaluation of academic productivity. Based on the empirical work of GOTO & SUZUKI [1989], ADAMS & GRILICHES [2000], GUELLEC & VAN POTTELSBERGHE DE LA POTTERIE [2004], and WANG & HUANG [2007], this study uses 3-year time lags. The input data set for 1990 and 2000 are matched with the output data set for 1993 and 2003, respectively.

Empirical results

The study focuses on a discussion of the changes in academic productivity in terms of quantity and the impact of scientific outcome. The variance in the patterns of academic productivity around the world has also been explored. In addition, an assessment regarding whether the countries with lower efficiencies could come up to or even close to the levels of the efficient countries has also been performed.

Table 1 lists the basic statistics of the sample from 1993 to 2003 in regard to overall academic productivity based on the publication share and citation share, and each of the four components, namely, (1) academic frontier change (AFC), (2) R&D efficiency change (EFF)(decomposed into pure R&D efficiency change (PE) and scale efficiency change(SE)), (3) human capital accumulation (Human), and (4) capital accumulation (R&D_inv.). The average contribution of academic frontier change to the citation share is about –43.95%, while that to the publication share is about –48.6%. In other words, the citation share would have declined by 43.95% and the publication share would have fallen by 48.6% if such a country's efficiency, human capital accumulation, and R&D

capital accumulation had been kept constant. That is, if there had been no further improvement in a country's academic environment, then the share of that country's academic contribution would have been reduced by more than 40%. This reveals the keen competition that exists among all the countries.

Table 1. Percentage change in decomposition indexes, 1993-2003

	Contribution to percentage change in growth of academic productivity					Percentage change in academic productivity
	PE[(1)]	SE[(1)]	AFC[(2)]	R&D_inv.[(3)]	Human[(4)]	
PS_{all} Mean(%)	32.7	25.6	–48.6	22.9	40.5	40.2
Std Dev	0.51	0.24	0.04	0.46	0.27	0.71
CS_{all} Mean(%)	40.8	13.1	–44.0	31.6	33.6	51.2
Std Dev	0.56	0.17	0.04	0.46	0.23	0.79

Note: (1) R&D efficiency change (EFF) is decomposed into pure R&D efficiency change (PE) and scale efficiency change(SE); (2) academic frontier change; (3) capital accumulation; (4) human capital accumulation.

As for the publication share, the extent of the contribution of human capital accumulation (40.46%) is approximately twice as high as that of capital accumulation (22.86%). That is to say, the benefit generated by the former is much greater than that derived from the latter. On the other hand, the citation share relies equally on both these two. This implies that capital accumulation plays a more important role in the citation share than in the publication share.

The contribution percentages of human capital accumulation, capital accumulation and pure R&D efficiency change, for all the countries' publication shares and citation shares, are illustrated in Figures 2 to 4, respectively. The horizontal axis represents the contribution percentage of the designated factor to the publication shares, and the vertical-axis the same in relation to the citation shares. Each dot represents a country. The position of the dot relative to the diagonal reveals whether the effort devoted to the publication has sufficient return in terms of its citation impact. If the representative dot of a country is beneath the diagonal, this means that such a factor more strongly influences the publication quantity than the citation quantity. On the contrary, the dot that locates above the diagonal indicates that the factor influences the publication share more than the citation share. Figures 2 and 3 show that both efficiency and capital accumulation affect the citation shares more strongly than the publication shares, whereas human capital accumulation exhibits the reverse tendency (Figure 4).

On the other hand, the horizontal and vertical dashed lines in Figure 2 to Figure 4 indicate the contributions of human capital deepening, capital accumulation, and pure R&D efficiency change to publication and citation growth all over the world, respectively.

The relative contributions of each factor to publication quantity and citation quality could be established by comparing the locations of these lines and dots of each country.

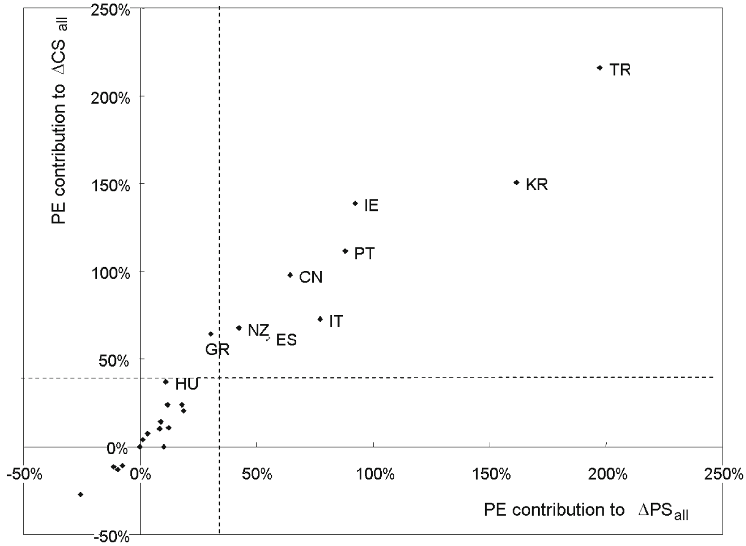

Figure 2. The contribution of pure R&D efficiency to publication and citation shares
Note: The abbreviation and full name of each country in this figure are listed in Table 2. ΔPS_{all}: incremental PS_{all}; ΔCS_{all}: incremental CS_{all}

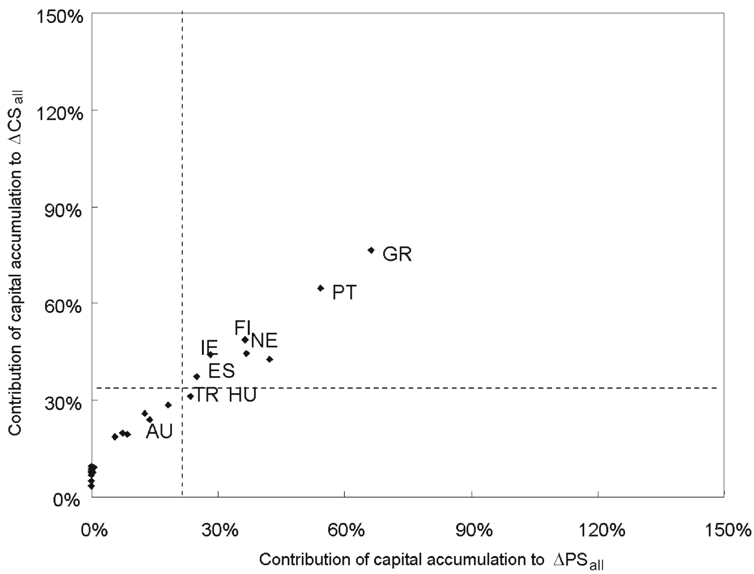

Figure 3. The contribution of capital accumulation to the publication and citation shares
Note: The abbreviation and full name of each country in this figure are listed in Table 2. ΔPS_{all}: incremental PS_{all}; ΔCS_{all}: incremental CS_{all}. The contribution of capital accumulation to ΔPS_{all} in China is 237.61%, while the contribution of capital accumulation to ΔCS_{all} in China is 242.95%

Dots above the horizontal or right to the vertical dashed lines show the higher contributions of the component than the world average. For example, as shown in Figure 2, the contribution of pure R&D efficiency change in Turkey, Korea, Italy, Ireland and China could have higher influence on both publication and citation than the world average. With the exception of Korea and Italy, the pure R&D efficiency change in these countries may play a more important role on citation than on publication.

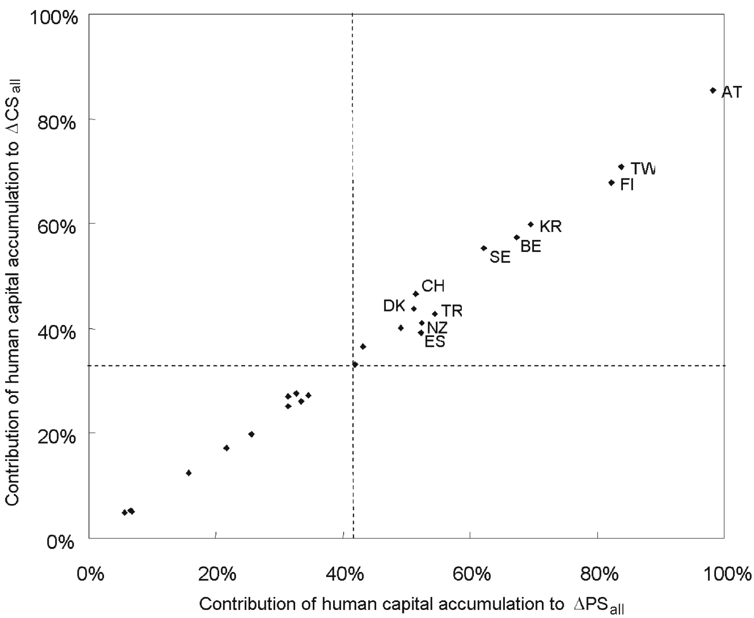

Figure 4. The contribution of human capital accumulation to the publication and citation shares
Note: The abbreviation and full name of each country in this figure are listed in Table 2. ΔPS_{all}: incremental PS_{all}; ΔCS_{all}: incremental CS_{all}.

Since the paper citation represents the influence of a country's academic output, the following international comparison is based on citation shares. Table 2 lists the initial efficiency (EFF) in 1993, the percentage change in the citation share, and each of the aforementioned components of each country. In general, most of the countries' citation shares increase during the period from 1993 to 2003 except for the United States, Canada, and France. The countries with rapid growth rates in their citation shares can be divided into two domains: one being the Asian countries, for example China, South Korea, Turkey, and Taiwan, which have the fastest growth rates in the world, and the other the developing countries in Europe, for example Portugal, Greece, Ireland and Spain. This implies the increasing impact and visibility of their academia, which may cause them to pursue the leading positions.

Figure 5 plots the array constructed from the initial efficiency and percentage change in citation shares. By resorting to the countries' locations and the languages used, several groups could be defined as follows:

1. The English speaking countries: New Zealand, Northern America, Australia, and the United Kingdom. Most of these countries have high initial efficiencies in 1993. During the 1993–2003 period, the increases in their citation shares are less than 10%; for some of them, such as the United States and Canada, the shares even went down. In regard to efficiency, there is little room for improvement in these countries. The efficiency in the case of Canada even declines. That is to say, to maintain their high citation shares, these countries have to steadily invest in their academia and also maintain a high level of efficiency.

2. Asian countries: Besides Japan, the initial efficiencies of Asian countries, including Taiwan, China, Korea, and Turkey, are mainly at a low level. From 1993 to 2003, the citation shares increase sharply, indicating the rapid growth of the research capabilities in these Asian countries. This increasing trend in the citation shares may be attributed to the improved efficiency among each of the countries, except for Japan and Taiwan. For South Korea, not only enhanced efficiency, but also an increase in human capital could be found. As for China, the large capital investment may have been the main reason for the improvement in the citation chares. As regards Taiwan, significant human capital accumulation plays a major role in boosting the improvement in academic productivity.

3. Europe: Except for Norway, most of the Nordic countries, such as Sweden, Finland and Denmark, possess high efficiency in 1993. Small developed countries such as the Netherlands and Switzerland also have high efficiency in 1993. The increases in their academic productivities are attributable to the expanding human capital accumulation. For those countries with low initial efficiencies in Europe, including Spain, Portugal, Ireland, Greece and Austria, the increases in the citation shares become significant during the period from 1993 to 2003, amounting to as much as a 50% expansion. The way they improve in terms of academic productivity is chiefly due to the promoted efficiencies, with notable R&D capital accumulation (countries such as Portugal, Ireland, and Greece) or human capital accumulation (countries such as Austria and Spain).

Figure 6 shows the different countries' efficiency distribution histogram. The distribution in this figure exhibits an upward trend over the period from 1993 to 2003, thereby suggesting a shift toward higher efficiency. This may imply that the growing tendency for those aforementioned developing countries to become more efficient during the past decade could be an important factor in narrowing the gap in academic productivity globally.

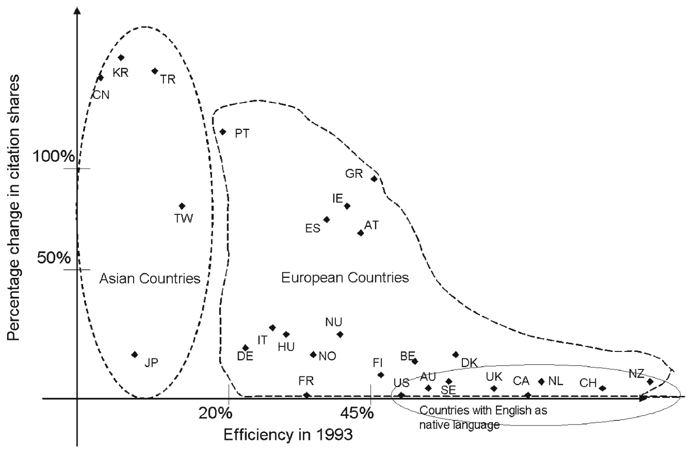

Figure 5. Distribution of each country's initial R&D efficiency (EFF) and percentage change in citation share
Note: The abbreviation and full name of each country in this figure are listed in Table 2.

Table 2. Percentage changes in decomposition indexes for 27 countries, 1993–2003

Country	Country (Abbr.)	EFF in 1993	% change in citation shares	Contribution to percentage change in citation shares of				
				PE change (%)	SE change (%)	AFC change (%)	R&D_inv. change (%)	Human change (%)
Australia	AU	0.51	9.26	7.61	31.72	–48.80	28.52	17.14
Austria	AT	0.41	47.72	14.25	4.37	–37.96	7.67	85.44
Belgium	BE	0.49	28.59	10.36	16.79	–41.99	9.27	57.40
Canada	CA	0.72	–18.20	–27.10	23.96	–46.02	19.62	40.19
China	CN	0.06	236.03	97.48	–16.32	–43.55	242.95	5.04
Denmark	DK	0.61	26.05	10.99	19.59	–44.39	18.80	43.75
Finland	FI	0.47	20.52	–11.38	6.35	–48.79	48.74	67.87
France	FR	0.34	–2.74	–10.67	34.18	–39.38	4.94	27.56
Germany	DE	0.22	13.80	32.12	33.58	–42.64	6.79	5.27
Greece	GR	0.46	96.17	64.04	–9.93	–43.53	76.56	33.18
Hungary	HU	0.30	20.59	36.86	9.74	–43.67	42.54	0
Ireland	IE	0.38	60.57	138.48	–28.50	–48.25	44.19	26.20
Italy	IT	0.30	25.81	72.71	29.57	–40.29	5.07	–10.38
Japan	JP	0.09	0.80	24.09	12.59	–46.50	7.78	25.13
Korea	KR	0.06	263.70	150.62	28.83	–44.04	25.92	59.88
Netherlands	NL	0.77	7.75	4.01	19.31	–40.42	6.77	36.50
New Zealand	NZ	1	5.08	0	0	–47.70	44.36	39.19
Norway	NO	0.36	26.26	23.85	36.62	–49.86	24.10	19.94
Portugal	PT	0.20	141.47	111.49	–0.69	–45.13	64.53	27.36
South Africa	NZ	0.24	2.67	67.38	–8.90	–39.81	6.70	4.85
Spain	ES	0.33	51.21	61.71	3.02	–51.01	31.38	41.02
Sweden	SE	0.59	3.89	–13.31	15.62	–39.16	9.69	55.32
Switzerland	CH	0.93	3.92	0	7.18	–36.04	3.34	46.68
Taiwan	TW	0.17	68.19	20.45	20.71	–43.36	19.56	70.84
Turkey	TR	0.10	258.51	215.79	15.08	–49.65	37.16	42.85
United Kingdom	UK	0.63	2.41	0	49.13	–43.35	7.81	12.45
United States	US	0.47	–18.59	0	0.64	–41.40	8.69	27.02

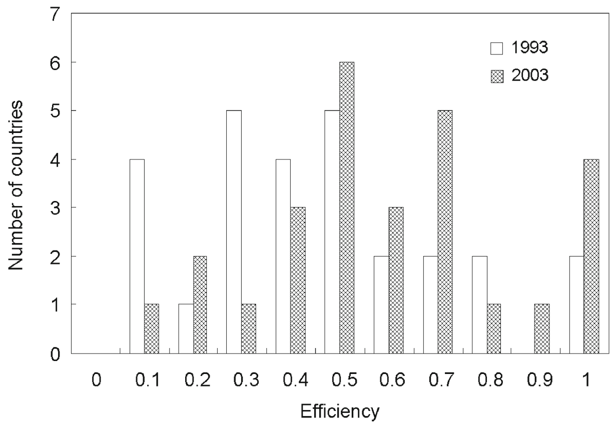

Figure 6. Efficiency distributions of citation shares

According to the initial efficiency in 1993, Table 3 categorizes the countries into two groups: one lists the countries with low efficiencies (the countries' efficiencies were below the median efficiency in 1993), whereas the other presents those countries with high efficiencies (the countries' efficiencies were higher than the median efficiency in 1993). From Table 3, the countries with lower initial efficiencies see their citation shares increase quite substantially (85.10%), as compared with those countries with higher efficiencies (19.65%).

Table 3. Comparison of countries with efficiencies higher/lower than the median in 1993

	% change in citation shares	Mean of contribution to % changes in citation shares		
		PE (% change)	Human (% change)	R&D_inv. (% change)
EFF in 1993 > median	19.65	14.13	42.02	23.86
EFF in 1993 ≤median	85.10	69.53	24.56	39.96
P-value	0.023**	0.006***	0.026**	0.2

Table 3 also shows that the productivity improvement of countries with lower initial efficiencies is mainly attributable to pure R&D efficiency changes (69.53%) and capital deepening (39.96%). Nevertheless, this is not the case when the contribution of human capital accumulation is considered. The countries with lower initial efficiencies have much less of an increase in human resources (24.56%) than those with higher initial efficiencies (42.02%).

Concluding remarks

The large amounts of resources devoted to basic research have gradually increased academic productivity all over the world. In addition to the countries that have dominated in this area in the past, a rising trend in the academia of those once poorly performed countries has been discovered, thereby narrowing the gap between laggers and leaders. The newly-developing Asian countries, such as South Korea, China, and Turkey, have exhibited significant progress in terms of both the quantity and quality of publications. These nations have not only raised their human and capital resources, but have also enhanced their efficiency in academic performance, thereby generating promising achievements.

Besides the Asian countries, it is worth mentioning the booms of some European countries. Impressive improvements in academic productivity have been found in emerging European countries such as Greece, Portugal, and Ireland.

This study also shows that each factor has a different impact on academic research. Human capital influences more on quantity of academic research than quality, while capital accumulation plays a more important role in the citation impact of academic research. Recently, more and more attention is being given to the quality and impact of the publications. Researchers have to face the challenges in terms of promoting the visibility and quality of their publications. This implies that the more attention paid to capital resources and enhanced efficiency may be necessary.

This paper provides additional insights into the actions that policy-makers could take to further promote academic research. In addition to financial support, human capital nurturing is also critical to long-term academic development. For any country that is in the catching-up stage, the government's policy should be to encourage innovative activities that enhance the efficient use of existing human and capital resources.

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