Comparison of Disciplinary Structure in Science between G7 and the BRIC countries by bibliometric methods

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Abstract

Using a collection of papers gathered from the Web of Science, and classifying disciplines through the JCR classification scheme, this paper compares the disciplinary structure of the G7 countries (representing high S&T level countries) and the BRIC countries (representing fast breaking countries in S&T) by bibliometric methods. It further analyzes the similarity and the balance of their disciplinary structure.

We found that: (1) Scientific and technological development is associated with national disciplinary structure. (2) The disciplinary structure of the BRIC countries becomes more and more similar to that of the G7 countries. (3) The disciplinary structure of the G7 countries is more balanced than that of the BRIC countries (4) In the G7 countries more emphasis goes to the life sciences, while BRIC countries focus on Physics, Chemistry, Mathematics and Engineering.

Introduction

The disciplinary structure of science for individual countries determines how resources and funds are distributed over disciplines. It is common understanding that the reasons for a country's particular disciplinary structure are complex. They are influenced by culture, political history and geographical influence (Almeida, 2009). It is also generally accepted that a country's disciplinary structure is highly related to its S&T development (Kozlowski et al., 1999; King, 2004; Kostoff et al., 2007). Therefore a government's S&T policy is often related to the disciplinary structure of its science.

Besides the influence originating from national policy, science systems have also strong self-organizing abilities. Here we consider the question if the S&T level can affect the formation of a country's disciplinary structure? Do similar S&T levels lead to or follow from similar disciplinary structures? Is there a difference in disciplinary structure between developed and developing countries?

The G7 countries are: the USA, UK, Canada, Germany, Japan, France and Italy. These countries have a high level of science and technology development. The BRIC countries are Brazil, Russia, India and China. These countries had a similar lower economic level in the past, but in the recent ten years, they achieved an amazing high speed of development especially in science and technology. Therefore, the G7 and the BRIC countries can be used to study two kinds of countries with different levels of development in S&T.

In bibliometric studies researchers used scientific publications to investigate disciplinary structure (Hu & Rousseau, 2009; Glänzel et al., 2008). Related investigations focused on the following specific topics:

1) Investigating changes in competitiveness of national science systems all through the world (Glänzel et al.,2008; Glänzel & Schlemmer, 2007);
2) Evaluating the scientific status of different countries (Hu & Rousseau, 2009);
3) Comparing differences between different types of countries (Kozlowski et al.,1999; King, 2004; Glänzel, 2000; Liang et al., 2006);
4) Evaluating local characteristics (Yue, 2008; Glänzel et al., 2006).

To achieve the above targets, relative indicators were usually applied to analyze and compare different disciplines (Frame, 1977; Glänzel et al., 2008; Hu & Rousseau, 2009). The Gini coefficient and the Lorenz curve are used to measure the evenness for many phenomenons,

such as biological species (Rousseau et al., 1999; Nijssen et al., 1998). In addition, radar plots are commonly used to demonstrate the balance or unevenness of disciplines (David, 2004; Glänzel, 2000; Yue, 2008). As we focus on the exact similarity between the disciplinary structures of different countries we will, however, not use such radar plats.
In this study, we try to detect and unveil the different disciplinary structure between two kinds of countries with different S&T level. Bibliometric methods were used here to compare the homogeneity (or heterogeneity) and balance (or polarization) of their disciplinary structure. Using these methods we describe existing differences between these countries.

Dataset and methods

Collection of dataset

The source data of this study comes from Thomson Reuter's Web of Science (WOS). We calculate the number of articles in every discipline for all countries in the world (including of course the G7 and BRIC countries) and the total number of articles of each country. A paper based on international collaboration was assigned to the country of its corresponding author, therefore, each paper is assigned to exactly one country.
As a working definition of 'a discipline' we just use the JCR journal classification, leading to more than 170 disciplines. Citation counts are not be used in this study as we want to focus on scientific production, not on visibility.

Definition of disciplinary structure

Let P refer to a number of articles, i to a country, j to a discipline and let us assume that we consider n disciplines in total. For discipline j, we define $\mathbf{R_{ij}}$ as the percentage of its number of articles in the total number of articles of country i:

$$\mathbf{R_{ij}} = \frac{\mathbf{P_{ij}}}{\mathbf{P_i}}$$

Then for country i, the disciplinary structure is denoted as vector $\mathbf{V_i}$:

$$\mathbf{V_i} = (\mathbf{R_{i1}}, \mathbf{R_{i2}}, \ldots \mathbf{R_{in}})$$

To compare the difference and explore the relationship between disciplinary structures among countries, we calculated the similarity among these countries based on their $\mathbf{V_i}$ vector. For example, for country i, in the year 1991, the disciplinary structure is denoted as follows:

$$\mathbf{V_{i1991}} = (\mathbf{R_{i1-1991}}, \mathbf{R_{i2-1991}}, \ldots \mathbf{R_{in-1991}})$$

Balance of the disciplinary structure

The research scales of different disciplines are often of a different order and hence they cannot be compared directly. To eliminate the influence of size, we use the indicator AI, defined below, as a normalized index (regarding the number of articles in the world as baseline):

$$\mathbf{AI_{ij}} = \frac{\mathbf{R_{ij}}}{\mathbf{R_{wj}}}$$

Here R_{wj} denotes the percentage of the number of articles in discipline j (in the world) in total article number of all disciplines (in the world).Then for each country, the Gini coefficient of AI index based on all disciplines is introduced to describe the balance of disciplinary structure. As it is commonly accepted, the threshold of Gini coefficient could be used to measure evenness. Here, if it is lower than 0.3, the disciplinary structure is comparative balanced; On the contrary, if the Gini coefficient of AI index exceeded 0.4 we take this as a sign that the disciplinary structure is polarized.

Method and used software

Cluster analysis and MDS are used for the comparison for homogeneity (or heterogeneity) of the disciplinary structure among different countries. Cluster analysis was performed by Gcluto-1.0 while MDS was performed by Ucinet 6.0.

Similarity measure

The cosine measure was applied to measure the similarity in disciplinary structure for one country in different time windows or for different countries in the same time window. For example, the similarity between 1991 and 2000 in country i is calculated as:

$$S_{i-1991:\ 2000} = \frac{\sum_{j=1}^{n} V_{ij1991} \times V_{ij2000}}{\sqrt{\sum_{j=1}^{n} (V_{ij1991})^2} \times \sqrt{\sum_{j=1}^{n} (V_{ij2000})^2}}$$

Results and discussion

Homogeneity and heterogeneity of disciplinary structure

1) For the G7 and some other European countries, the disciplinary structure shows a high homogeneity, while the BRIC countries show heterogeneity

Figure 1 and figure 2 show respectively that there is a cluster including almost all developed countries (with the G7 and some other European countries) which have a higher similarity based on V_i, meaning that they have a homogeneous disciplinary structure. Japan is the only Asian country that is situated near the group of Western developed countries, showing that its disciplinary structure is totally different from that of other Asian countries.

BRIC countries are dispersed in figures 1 and 2. In 1991, USSR and China belonged to the same cluster. They were both far away from the G7 group. India was located in the same group as two Eastern European countries. The disciplinary structure of Brazil was completely different from all other countries. In 2009, China and India came into the same cluster, while Brazil and Russia formed singleton clusters, away from the others.

2) From 1991 to 2009, the BRIC countries (except Russia) adjusted their disciplinary structure, coming much closer to the USA and other scientifically strong countries

The cosine correlation coefficient for each country is displayed in table 1. This table makes it possible to look at exact similarity values in detail (something that is not possible on a MDS plot). Comparing the cosine correlation coefficient in 1991and 2009 between the G7 and the BRIC countries, we find it is interesting to see that in 2009 the disciplinary structure of the BRIC countries came nearer to that of the G7 countries. Take Brazil as an example: in 1991, the similarity between Brazil and the G7 countries lies between 0.62 and 0.72, while in 2009 it changed from 0.88 to 0.97. In addition, similar changes happened to other BRIC countries.

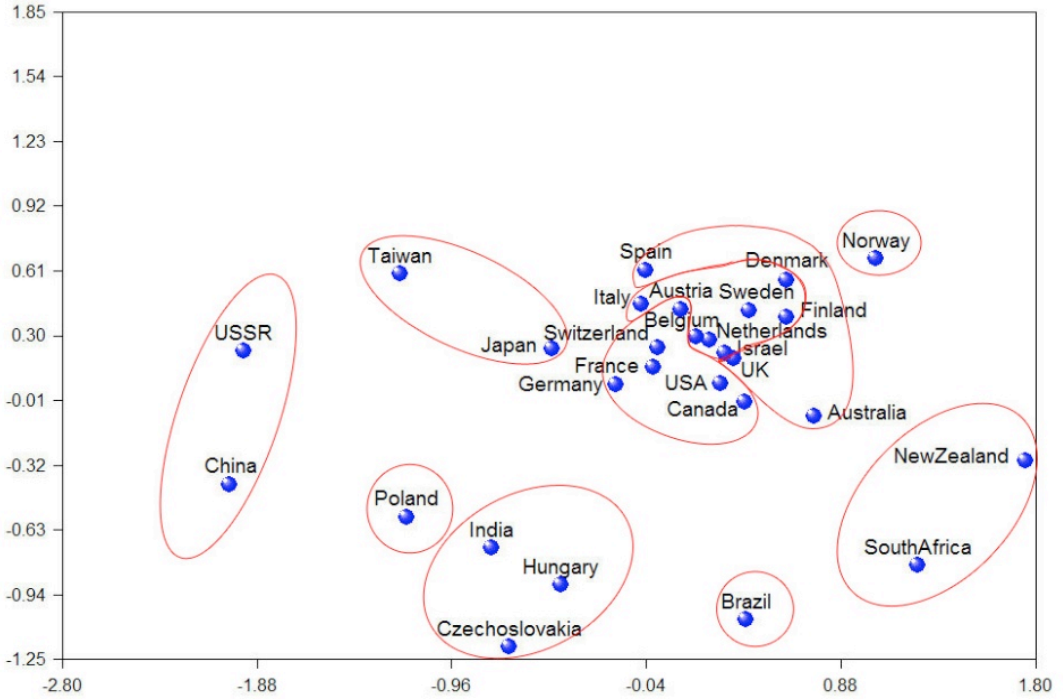


Figure 1 MDS and cluster analysis of disciplinary structure of main countries (1991)

3) The disciplinary structure of some countries is related to geo-political characteristics

Figure 1 and figure 2 demonstrate that in 1991 and 2009, Eastern European countries were located in each other's neighbourhood. In 2009, Turkey and Greece stayed in the same cluster, Singapore, South Korea and Taiwan also belonged to one group. In addition, in 1991 China still had a strong similarity with the USSR because of its similar social and political system. But things changed very much during recent years, and the MDS analysis for 2009 shows that the disciplinary structure of China is now very different from Russia's.

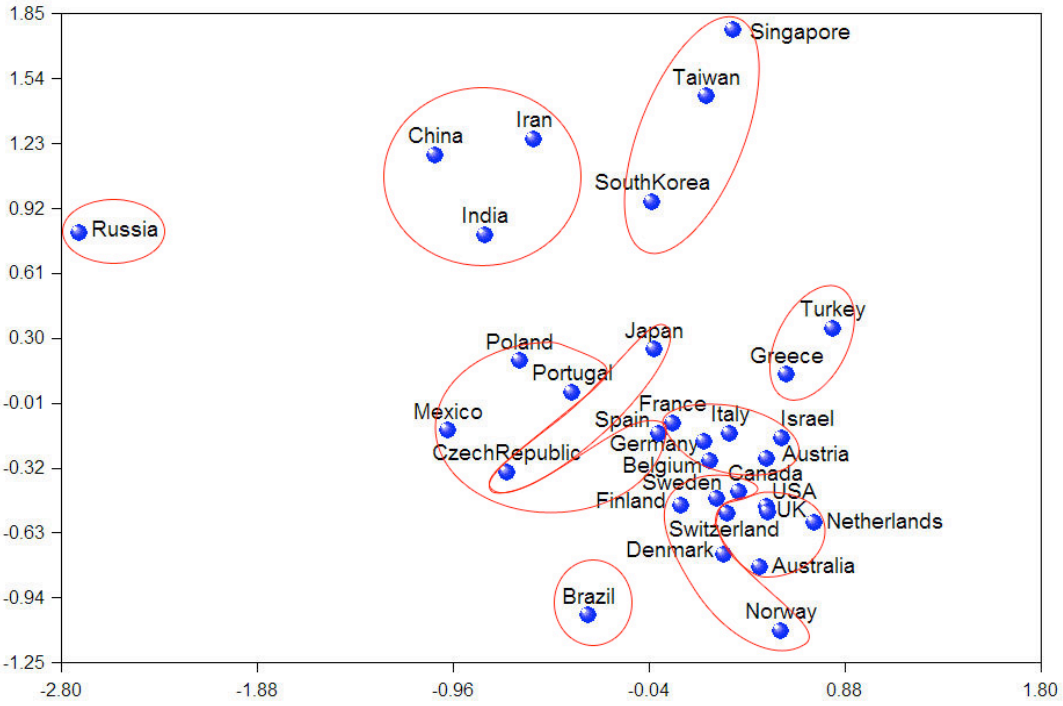


Figure 2 MDS and cluster analysis of disciplinary structure of main countries(2009)

Table1. Cosine correlation coefficients between the G7 and the BRIC countries (1991& 2009)

1991 \ 2009	USA	GBR	GER	FRA	JPN	ITA	CAN	NED	SUI	ESP	AUS	RUS	CHN	IND	BRA
USA	-	0.97	0.95	0.93	0.88	0.95	0.97	0.96	0.93	0.90	0.92	0.54	0.62	0.71	0.84
GBR	0.86	-	0.93	0.92	0.85	0.91	0.95	0.94	0.95	0.90	0.94	0.55	0.62	0.71	0.85
GER	0.88	0.85	-	0.96	0.93	0.94	0.92	0.93	0.93	0.91	0.87	0.66	0.72	0.78	0.82
FRA	0.91	0.90	0.94	-	0.93	0.94	0.93	0.89	0.91	0.94	0.87	0.73	0.79	0.83	0.82
JPN	0.84	0.72	0.90	0.87	-	0.90	0.87	0.84	0.85	0.88	0.79	0.71	0.81	0.85	0.78
ITA	0.85	0.78	0.86	0.90	0.86	-	0.92	0.95	0.88	0.91	0.84	0.58	0.64	0.71	0.80
CAN	0.95	0.87	0.89	0.90	0.82	0.85	-	0.93	0.92	0.93	0.94	0.56	0.66	0.72	0.84
NED	0.90	0.84	0.90	0.92	0.86	0.93	0.91	-	0.89	0.88	0.89	0.46	0.55	0.65	0.81
SUI	0.90	0.89	0.93	0.94	0.85	0.86	0.88	0.90	-	0.89	0.92	0.60	0.65	0.73	0.83
ESP	0.77	0.90	0.86	0.86	0.73	0.76	0.81	0.81	0.85	-	0.89	0.64	0.76	0.82	0.86
AUS	0.82	0.91	0.80	0.82	0.67	0.70	0.90	0.81	0.82	0.86	-	0.52	0.61	0.68	0.84
RUS	0.66	0.69	0.78	0.78	0.70	0.61	0.63	0.59	0.74	0.66	0.59	-	0.84	0.76	0.52
CHN	0.54	0.53	0.66	0.68	0.63	0.53	0.51	0.49	0.62	0.51	0.46	0.89	-	0.91	0.62
IND	0.68	0.61	0.80	0.73	0.78	0.62	0.71	0.67	0.70	0.66	0.68	0.73	0.73	-	0.75
BRA	0.69	0.63	0.67	0.70	0.62	0.66	0.72	0.71	0.66	0.62	0.70	0.56	0.47	0.69	-

The disciplinary advantage of the G7 versus the BRIC countries

Based on the above analysis we see that there is a difference in disciplinary structure between the G7 and the BRIC countries. To further reveal detailed information, we choose, for each country, the top 10 disciplines based on their AI-value. Each of these disciplines is then assigned to four major subjects: life sciences, agriculture, mathematics-physics-chemistry - engineering and earth science-environmental science-energy (see Figures 3 and 4).

1) *For the G7 countries one may say that the life sciences dominate, while for the BRIC countries (except Brazil), basic research, such as mathematics-physics-chemistry-engineering is advantaged.*

For the USA, in 1991, 70% of the top 10 AI disciplines belong to the life sciences and in 2009, all the top10 AI disciplines belong to the life sciences. The UK is very similar to the USA. Brazil is an exception among the BRIC countries, as Brazil also focuses on life sciences. It is obvious that China and Russia pay more attention to basic research and engineering applications. In 1991 but also in 2009, all the top 10 AI disciplines are related to mathematics, physics, chemistry or engineering.

2) Comparing to 1991, there is a trend that by 2009 life science research has even increased its relative importance in the G7 countries and Brazil, while for the other BRIC countries it changed only slightly.

In 1991 only 10% of the TOP10 AI disciplines in Germany belonged to the life sciences, while this rate has increased to 60%. Among the BRIC countries we notice India that no life sciences among its top subjects in 1991; now this has slightly increased to about 10%.The structure of China and Russia has not changed at all between 1991 and 2009.

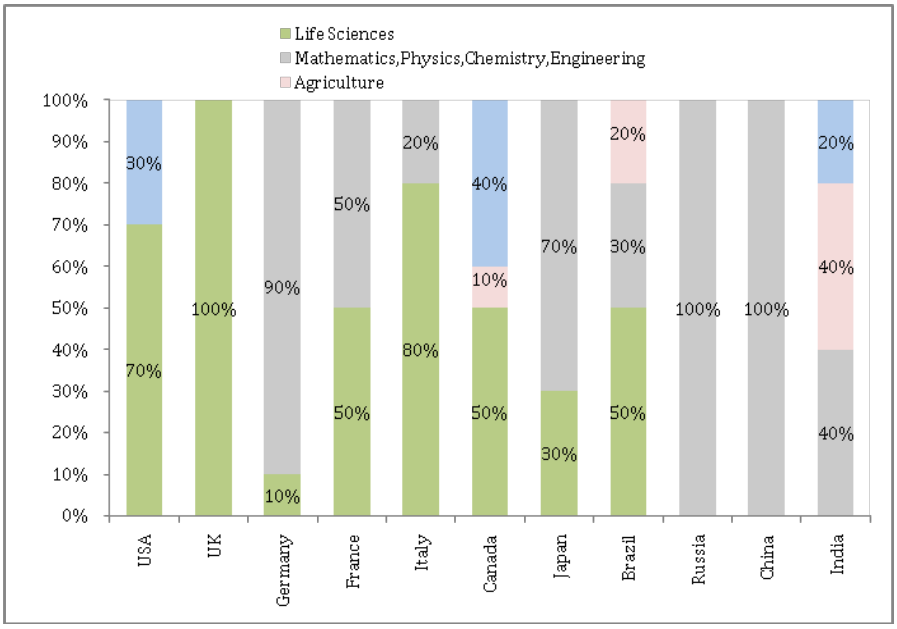


Figure3. Top subjects of the G7 and the BRIC countries(1991)

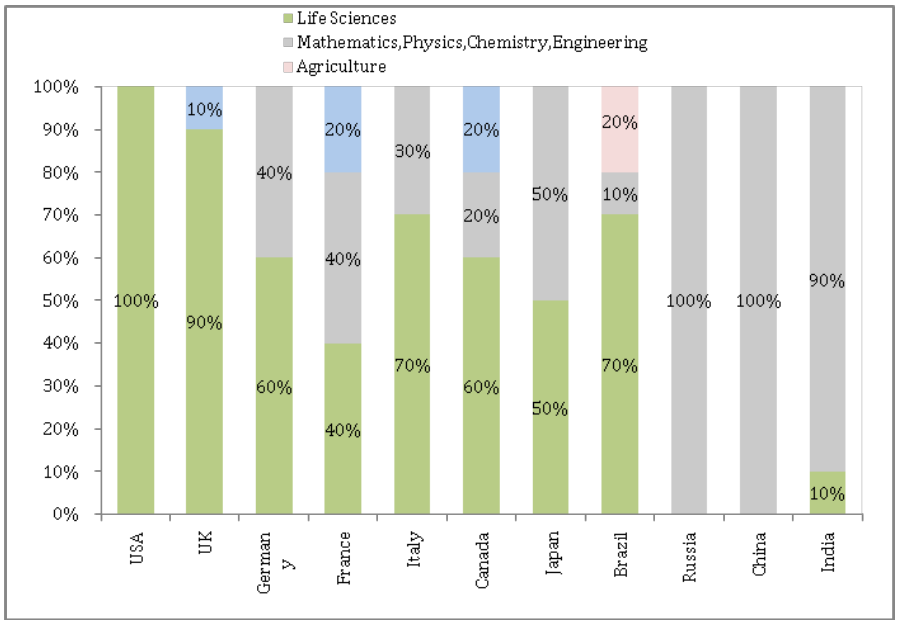


Figure4. Top subjects of the G7 and the BRIC countries(2009)

Evolution of homogeneity and heterogeneity of the disciplinary structure

1. *Considering the whole period 1991-2000,we see that most changes occurred in the first part, while the disciplinary structure stayed more stable over the latest ten years*

Figure 5 shows the changes in similarity of disciplinary structure between 1991-2000 and 2000-2009. For all countries, G7 country or BRIC country, its value of $S_{i-1991:2000}$ is much higher than that of $S_{i-2000:2009}$ which means that changes happened mostly in the first ten year period.

2. *Especially the BRIC countries have adjusted their disciplinary structure in 1991-2000*

Figure 5 shows that for the *BRIC countries*, especially China and Brazil, $S_{i-1991:2000}$ is much lower than $S_{i-2000:2009}$.

3. *In the recent 20 years, the disciplinary structure of the G7 countries changed slightly, showing that they had already reached a stable structure*

From Figure 5 we see that while changes among BRIC countries in different time window vary very much according to the time window, for G7 countries these changes are rather small. For instance: Brazil changed from 0.701 to 0.847 while the USA changed only from 0.902 to 0.908.

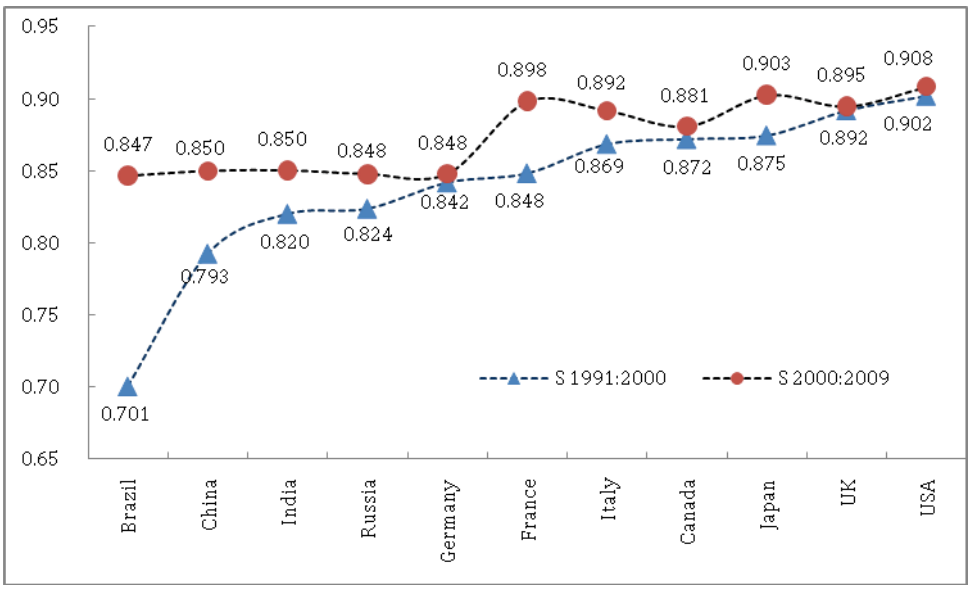


Figure5. $S_{i-1991:2000}$ and $S_{i-2000:2009}$ for the G7 and the BRIC countries

Balance or polarization of disciplinary structure

For each country, it is difficult to decide if balance or polarization of disciplinary structure is the better. Yet, experience seems to have shown that a skewed structure can do harm to sustained development in S&T. To detect the above difference between G7 and BRIC countries, we drew Lorenz curves for each country based on its AI-value and calculated the Gini coefficient of AI-value.

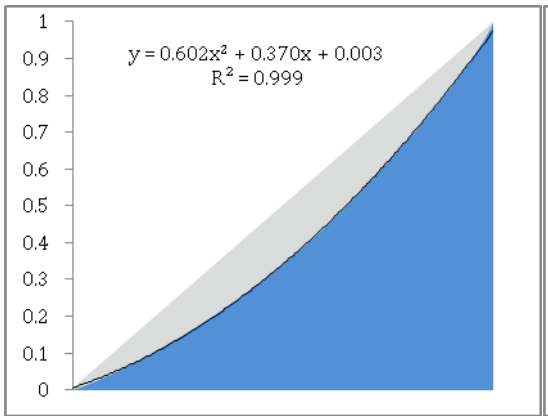
In recent years the disciplinary structure of the G7 countries is more balanced than that of the BRIC countries.

Figure 6 and table 2 show Lorenz curves and the Gini coefficient of AI index for the G7 and the BRIC countries.

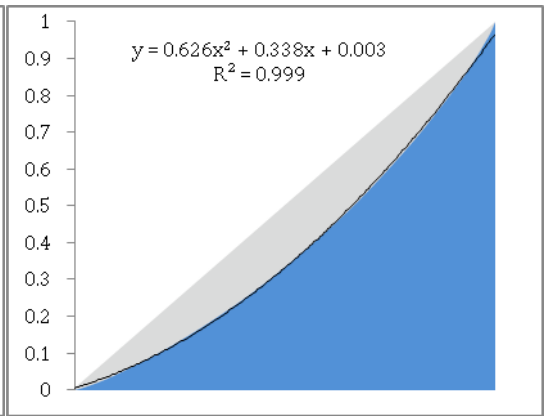
In 1991, the Gini coefficient of the G7 countries (except Japan) was from 0.182-0.346. In 2009, the range of the Gini coefficient was from 0.158-0.355. It indicates that the disciplinary structure of the G7 countries is comparative balanced.

For the BRIC countries in 1991, the Gini coefficient was from 0.471-0.642, while in 2009, it was from 0.360-0.647, which representing that the disciplinary structure of the BRIC countries is polarized.

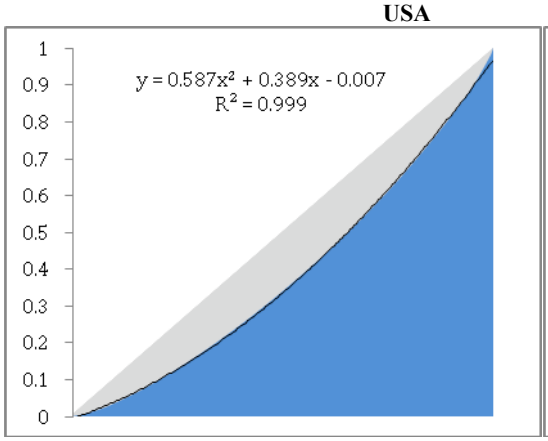
The Gini coefficient of the G7 countries is much less than that of the BRIC countries, showing that the disciplinary structure of the G7 countries is more balanced than that of BRIC countries.



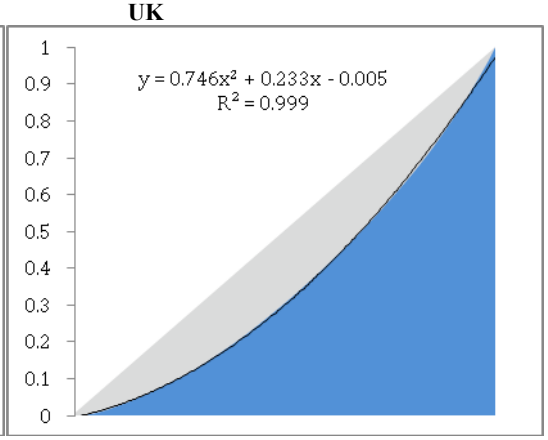
USA



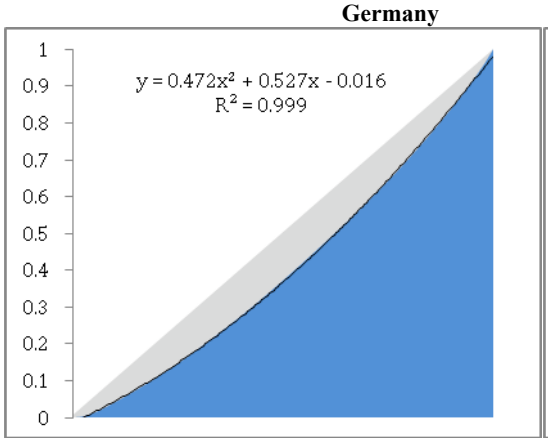
UK



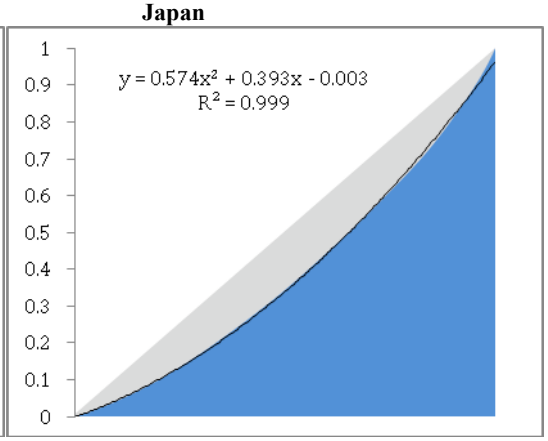
Germany



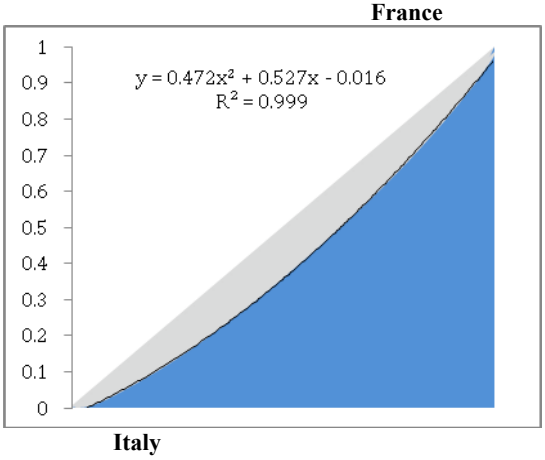
Japan



France



Canada



Italy

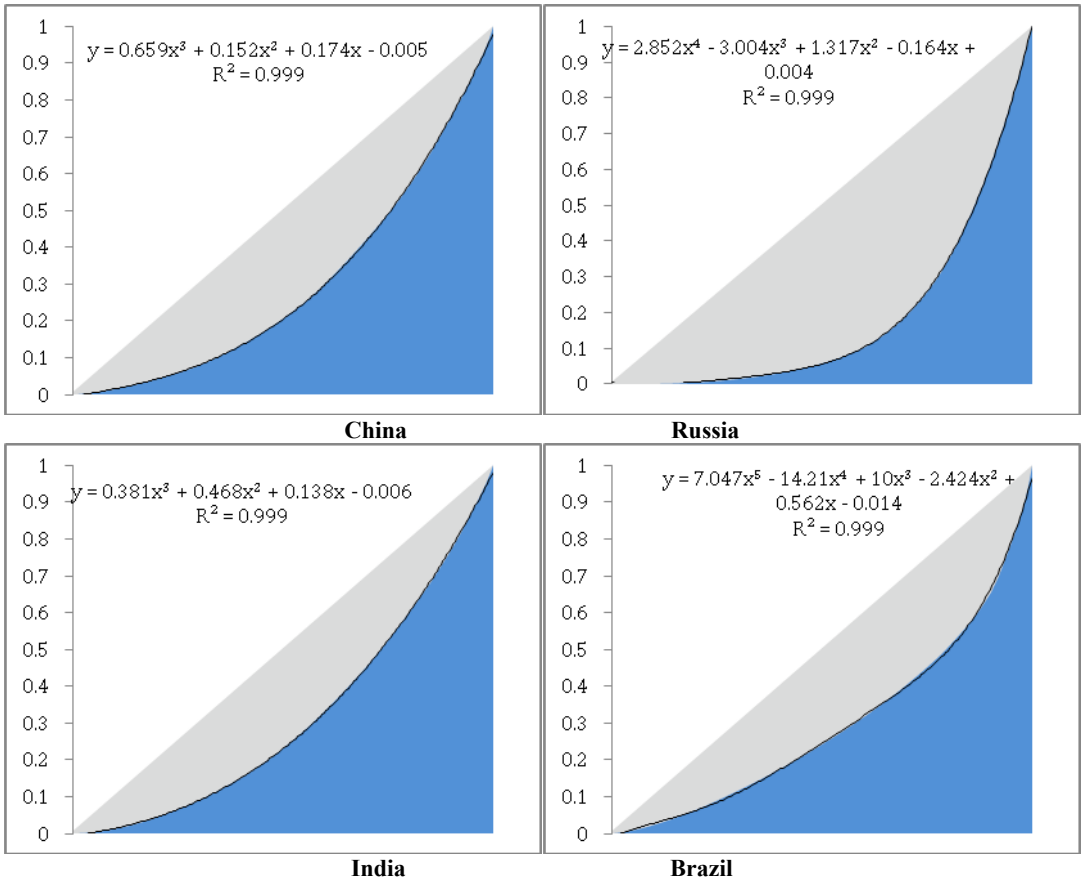


Figure 6. Lorenz curves of AI index of the G7 and the BRIC countries (2009)

Compared to evenness of the disciplinary structure for each country in 1991, 2000 and 2009, the G7countries showed different characteristic respectively, while BRIC countries showed same evolution: polarization-balance-balance, hence their evolution tends to the balanced side.

Though the G7 countries showed a balanced characteristic compared to BRIC countries, while in different time window, they showed individual aspect respectively based on table 2. For example, USA showed more and more polarization from 1991 to 2009, while for UK, the Gini coefficient was 0.227, 0.216 and 0.245 in 1991, 2000, 2009, which showed polarization-balance-polarization.

Different from G7 country, BRIC countries changed in a different way, namely: high-low-lower in three time points. The disciplinary structure of China was polarized in 1991(the Gini coefficient of AI index is 0.568), then China adjusted its disciplinary structure greatly in the recent 20 years (compared to itself, but still higher than Brazil and India) In 2009 the Gini coefficient of the AI index decreased to 0.395 showing that the disciplinary structure tended to balanced.

Table2.The Gini coefficient of the AI index for G7 and BRIC countries

Country	1991	2000	2009	Country	1991	2000	2009
USA	0.182	0.187	0.229	ITALY	0.346	0.237	0.218
UK	0.227	0.216	0.245	CHINA	0.568	0.459	0.395
GERMANY	0.275	0.222	0.220	USSR	0.642	0.646	0.647
JAPAN	0.445	0.291	0.270	INDIA	0.471	0.484	0.360
FRANCE	0.297	0.170	0.158	BRAZIL	0.568	0.435	0.389
CANADA	0.234	0.224	0.355				

Table 3 shows detailed information related to balance or polarization of the disciplinary structure.

Based on the above analysis, we know that the disciplinary structure of the G7 countries was more balanced than that of the BRIC countries. Table 3 provides detailed statistics about this. From this table we observe that AI value of more than 90% of the disciplines of the G7 countries (except Japan, with a percentage of 83.95%) is around the AI baseline ($0.5 < AI < 2$), which explores most disciplines of G7 countries are comparative balanced.
Russia is the most polarized country among all the countries studied here: only 32.1% of its disciplines are comparative balanced; furthermore, the ratio of disciplines with $AI < 0.5$ is 44.4%, much higher than that of others.
Among the BRIC countries, China is the second one following Russia, there is about 33.3% disciplines which has a lower AI score ($AI < 0.5$).

Table3. Distribution of AI value of the G7 and the BRIC countries (2009)

country	AI > 2		AI < 0.5		0.5 < AI < 2	
	Number of disciplines	ratio	Number of disciplines	ratio	Number of disciplines	ratio
USA	0	0.00%	7	8.64%	74	91.36%
UK	2	2.47%	5	6.17%	74	91.36%
Germany	1	1.23%	3	3.70%	77	95.06%
France	0	0.00%	0	0.00%	81	100.00%
Italy	1	1.23%	3	3.70%	77	95.06%
Canada	1	1.23%	4	4.94%	76	93.83%
Japan	1	1.23%	12	14.81%	68	83.95%
Russia	19	23.46%	36	44.44%	26	32.10%
China	9	11.11%	27	33.33%	45	55.56%
Brazil	2	2.47%	10	12.35%	69	85.19%
India	6	7.41%	21	25.93%	54	66.67%

Conclusion

Based on this study, comparing the G7 and the BRIC countries, we conclude that there exists a relationship between the national disciplinary structure and the S&T level. The study presented here illustrates the following conclusions:
Firstly, there is a similar disciplinary structure among all G7 countries (also with other high S&T countries), while the BRIC countries have individually more pronounced structures. The structures of the USA and the UK appear to be the baseline for BRIC countries. The correlation coefficient among BRIC countries and the USA increased from 1991 to 2009, showing that the BRIC countries seem to adjust their disciplinary structure to that of the G7 countries. In addition, the G7 countries focus on the life sciences, and this much more than the BRIC countries. BRIC countries pay more attention to basic research. Brazil is somewhat of an exception among the BRIC countries. This country, although differing from the G7 countries, does focus on the life sciences.
Secondly, compared to the G7 countries, the disciplinary structure of the BRIC countries is more polarized. We detected that from 1991 to 2009, especially before 2000, the BRIC countries experienced great changes in their disciplinary structure and showed a trend from an unbalanced structure to a more balanced one.
Although the G7 countries keep a comparative stable disciplinary structure over the recent 20 years, we found that in 1991, 2000 and 2009, G7 countries showed different characteristic respectively: the Gini coefficient of some G7 countries increased slightly, while the index of some G7 countries was high-low-high.
Some polarization might be a good thing for a country, but too much polarization, and also too much balance appears to be harmful to its scientific development. Therefore the formation of a country's disciplinary structure should be seen as a dynamic process. For the G7

countries, this dynamic process moves only slowly, while for the BRIC countries the process is much more vehement. In these countries reconstructing the disciplinary structure seems to go hand in hand with a strong development of S&T.

Acknowledgement

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