中国科学院科技战略咨询研究院
Institutes of Science and Development, Chinese Academy of Sciences

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2021

Research Fronts: Active Fields, Leading Countries

Institutes of Science and Development,
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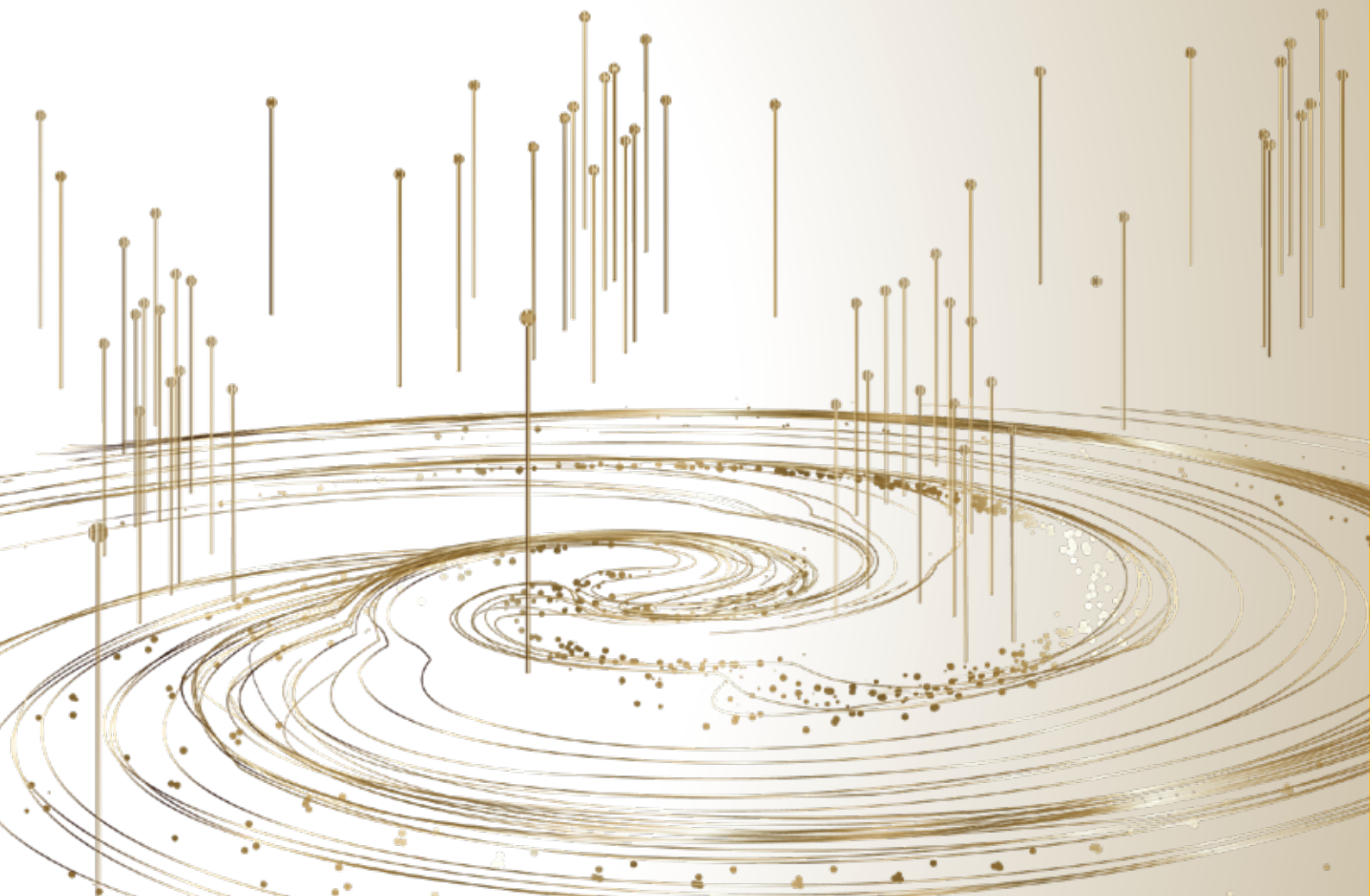


Science and technology are universal and epochal, and the development of science and technology must be viewed from a global perspective. At present, major breakthroughs and accelerated applications of technological innovation have been instrumental in reshaping the global economic structure and transforming the arena of industrial and economic competition. The "Research Fronts 2021" report is a prequel to another survey, "Research Fronts 2021: Active Fields, Leading Countries", which selects and discusses 110 hot fronts and 61 emerging fronts in 11 broad research areas. Based on the findings of "Research Fronts 2021", this second report uses the Research Leadership Index to assess the research activity of the world's major countries and to observe how that activity, in the face of global competition in innovation and technological advancement, is demonstrated in these Research Fronts.

110
Hot Research Fronts

61
Emerging Research Fronts

1 Methodology

1.1 The logic model of Research Leadership Index (RLI)

The Research Leadership Index (RLI) is a comprehensive evaluation measure to determine the degree of activity in Research Fronts. Since a Research Front itself is composed of a group of highly cited core papers along with subsequent papers that cite the core literature, the design of the Research Leadership Index takes into account the numbers of the core papers and citing papers, as well as their respective citations. These calculations underlie two indicators: Output Share and Citation Share. The logical model of Research Leadership Index (RLI) is shown in Figure 1.

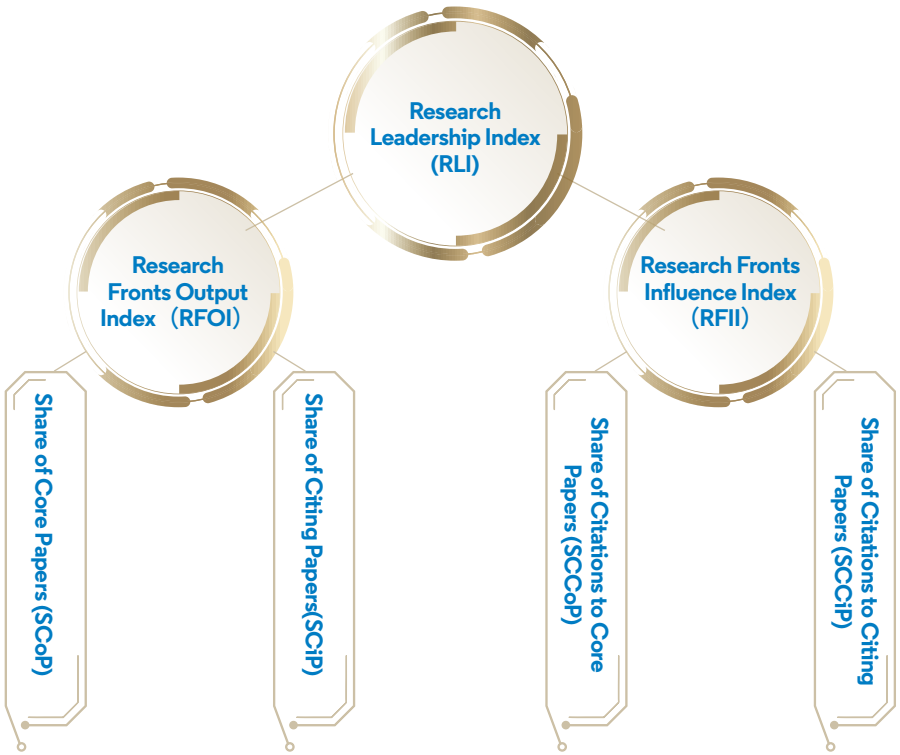


Figure 1. The logic model of Research Leadership Index (RLI)

The entities measured by the Research Leadership Index can be countries, cities, institutions, laboratories, teams, and individual scientists. Each entity can be measured at three levels: Research Front level, area level, and a level within the context of 11 broad research areas.

1.2 Research Leadership Index of country (RLIC)

This report calculates the Research Leadership Index of main countries at the Research Front level, area level, and the level of all 11 broad research areas. Based on that, the report determined the degree of activity in innovation and its pattern within the main countries as reflected in Research Fronts, and revealed the sources of research vitality in various countries. The methods for calculation and analysis are as follows:

1.2.1 Research Leadership Index of a country in a Research Front (RLI_{Cij})

The Research Leadership Index measures a country's degree of activity as reflected in Research Fronts, including two aspects of the output and citation influence of papers in the fronts. The equation for Research Leadership Index of Country in a Research Front (RLI_{Cij}) is:

$$\mathrm{RLI}_{Cij} = \mathrm{RFOI}_{Cij} + \mathrm{RFII}_{Cij} = \frac{CoP_{ij}}{CoP_j} + \frac{CiP_{ij}}{CiP_j} + \frac{CoC_{ij}}{CoC_j} + \frac{CiC_{ij}}{CiC_j}$$

$RFOI_{Cij}$ is the Research Fronts Output Index of a country, $RFII_{Cij}$ is the Research Fronts Influence Index of a country, *j* represents the Research Front, and *i* represents each country.

(1) Research Fronts Output Index of a country ($RFOI_{Cij}$)

The Research Fronts Output Index of a country ($RFOI_{Cij}$) is the relative share of the number of papers (core papers and citing papers) contributed by a country to the literature that constitutes a Research Front. $RFOI_{Cij}$ equals the sum of the two indicators $SCoP_{Cij}$ and $SCiP_{Cij}$

$$\mathrm{RFOI}_{Cij} = \mathrm{SCoP}_{Cij} + \mathrm{SCiP}_{Cij} = \frac{CoP_{ij}}{CoP_j} + \frac{CiP_{ij}}{CiP_j}$$

A country's Share of Core Papers in a Research Front ($SCoP_{Cij}$) indicates the percentage of CoP_{ij} in CoP_j.

$$\mathrm{SCoP}_{Cij} = \frac{CoP_{ij}}{CoP_j}$$

CoP_{ij} represents the number of core papers published by country *i* in Research Front *j*; CoP_j represents the number of core papers in Research Front j.

A Country's Share of Citing Paper in a Research Front ($SCiP_{Cij}$) indicates the percentage of CiP_{ij} in CiP_j.

$$\mathrm{SCiP}_{Cij} = \frac{CiP_{ij}}{CiP_j}$$

CiP_{ij} represents the number of citing papers published by country *i* in Research Front *j*; CiP_j represents the number of Citing papers in Research Front *j*.

(2) Research Fronts Influence Index of a country ($RFII_{Cij}$)

The Research Fronts Influence Index of a country ($RFII_{Cij}$) is the relative share of the citation of papers (core and citing) that a country contributed in a Research Front. $RFII_{Cij}$ equals the sum of the two indicators $SCCoP_{Cij}$ and $SCCiP_{Cij}$.

$$\mathrm{RFII}_{Cij} = SCCoP_{Cij} + SCCiP_{Cij} = \frac{CoC_{ij}}{CoC_j} + \frac{CiC_{ij}}{CiC_j}$$

Country's Share of Core Paper Citation for a Research Front ($SCCoP_{Cij}$) indicates the percentage of CoC_{ij} in CoC_j.

$$\mathrm{SCCoP}_{Cij} = \frac{CoC_{ij}}{CoC_j}$$

CoC_{ij} represents the citation of core papers published by country *i* in Research Front j; CoC_j represents the citation of core papers in Research Front *j*.

The measure known as Country's Share of Citation to Citing Paper in a Research Front ($SCCiP_{Cij}$) indicates the percentage of CiC_{ij} in CiC_j.

$$\mathrm{SCCiP}_{Cij} = \frac{CiC_{ij}}{CiC_j}$$

CiC_{ij} represents the citation of citing papers published by country *i* in Research Front *j*; CiC_j represents the citation of citing papers in Research Front *j*.

1.2.2 Research Leadership Index of a country in an area (RLI_{Cik})

The Research Leadership Index of country *i* in area *k* (RLI_{Cik}) is the summation of the Research Leadership Index of country *i* (RLI_{Cij}) in n Research Fronts in area *k*. *k* is the one area, n is the total number of areas.

The formula for RLI_{Cik} is as follows:

$$\mathrm{RLI}_{ik} = \mathrm{RFOI}_{Cik} + \mathrm{RFII}_{Cik} == \sum_{j=1}^{n} \frac{CoP_{ij}}{CoP_j} + \sum_{j=1}^{n} \frac{CiP_{ij}}{CiP_j} + \sum_{j=1}^{n} \frac{CoC_{ij}}{CoC_j} + \sum_{j=1}^{n} \frac{CiC_{ij}}{CiC_j}$$

RLI_{Cik} is equal to the sum of the two indicators $RFOI_{Cik}$ and $RFII_{Cik}$.

(1) Research Fronts Output Index of a country in an area ($RFOI_{Cik}$)

The Research Fronts Output Index of a country in an area ($RFOI_{Cik}$) is the relative share of the number of papers (core and citing) contributed by a country to an area composed of n Research Fronts. $RFOI_{Cik}$ is equal to the sum of the two indicators $SCoP_{Cik}$ and $SCiP_{Cik}$.

$$\mathrm{RFOI}_{Cik} = \mathrm{SCoP}_{Cik} + \mathrm{SCiP}_{Cik} = \sum_{j=1}^{n} \frac{CoP_{ij}}{CoP_j} + \sum_{j=1}^{n} \frac{CiP_{ij}}{CiP_j}$$

The formula for a country's Share of Core Papers in an area ($SCoP_{Cik}$) is below:

$$\mathrm{SCoP}_{Cik} = \sum_{j=1}^{n} \frac{CoP_{ij}}{CoP_j}$$

The formula for a country's Share of Citing Papers in an area ($SCiP_{Cik}$) is:

$$\mathrm{SCiP}_{Cik} = \sum_{j=1}^{n} \frac{CiP_{ij}}{CiP_j}$$

(2) Research Fronts Influence Index of a country in an area ($RFII_{Cik}$)

The Research Fronts Influence Index of a country in an area ($RFII_{Cik}$) is the relative share of the citation of papers (core and citing) contributed by a country to an area composed of n Research Fronts. $RFII_{Cik}$ equals the sum of the two indicators $SCCoP_{Cik}$ and $SCCiP_{Cik}$.

$$\mathrm{RFII}_{Cik} = \mathrm{SCCoP}_{Cik} + \mathrm{SCCiP}_{Cik} = \sum_{j=1}^{n} \frac{CoC_{ij}}{CoC_j} + \sum_{j=1}^{n} \frac{CiC_{ij}}{CiC_j}$$

The formula for a country's Share of Citations to Core Papers in an area ($SCCoP_{Cik}$) is:

$$\mathrm{SCCoP}_{Cik} = \sum_{j=1}^{n} \frac{CoC_{ij}}{CoC_j}$$

Below, the formula for a country's Share of Citations to Citing Papers in an area ($CiCS_{Cik}$):

$$\mathrm{SCCiP}_{Cik} = \sum_{j=1}^{n} \frac{CiC_{ij}}{CiC_j}$$

1.2.3 Research Leadership Index of a country in 11 broad research areas (RLI_{Ci})

The Research Leadership Index of a country in 11 broad research areas (RLI_{Ci}) represents the scores of RLI_{Cik} of 11 broad research areas added together. The index is a comprehensive evaluative index to measure the degree of activity of a country based on its contribution to 11 broad research areas comprising 171 Research Fronts.

$$\mathrm{RLI}_{Ci} = \mathrm{RFOI}_{Ci} + \mathrm{RFII}_{Ci} = \sum_{k=1}^{10}\sum_{j=1}^{n} \frac{CoP_{ij}}{CoP_j} + \sum_{k=1}^{10}\sum_{j=1}^{n} \frac{CiP_{ij}}{CiP_j} + \sum_{k=1}^{10}\sum_{j=1}^{n} \frac{CoC_{ij}}{CoC_j} + \sum_{k=1}^{10}\sum_{j=1}^{n} \frac{CiC_{ij}}{CiC_j}$$

RLI_{Ci} is equal to the sum of the two indicators $RFOI_{Ci}$ and $RFII_{Ci}$.

(1) Research Fronts Output Index of a country in 11 broad research areas ($RFOI_{Ci}$)

The Research Fronts Output Index of a country in 11 broad research areas ($RFOI_{Ci}$) is the sum of the relative share of the number of papers (core and citing) contributed by a country to 11 broad research areas composed of 171 Research Fronts. $RFOI_{Ci}$ is equal to the sum of the two indicators $SCoP_{Ci}$ and $SCiP_{Ci}$.

$$\mathrm{RFOI}_{Ci} = \mathrm{SCoP}_{Ci} + \mathrm{SCiP}_{Ci} = \sum_{k=1}^{10}\sum_{j=1}^{n} \frac{CoP_{ij}}{CoP_j} + \sum_{k=1}^{10}\sum_{j=1}^{n} \frac{CiP_{ij}}{CiP_j}$$

The formula for a country's Share of Core Papers in 11 broad research areas ($SCoP_{Ci}$) is as follows:

$$\mathrm{SCoP}_{Ci} = \sum_{k=1}^{10}\sum_{j=1}^{n} \frac{CoP_{ij}}{CoP_j}$$

The formula for a country's Share of Citing Papers in 11 broad research areas ($SCiP_{Ci}$) is:

$$\mathrm{SCiP}_{Ci} = \sum_{k=1}^{10} \sum_{j=1}^{n} \frac{CiP_{ij}}{CiP_j}$$

(2) Research Fronts Influence Index of a country in 11 broad research areas ($RFII_{Ci}$)

The Research Fronts Influence Index of a country in 11 broad research areas ($RFII_{Ci}$) is the sum of the relative share of the citation of papers (core and citing) contributed by a country to 11 broad research areas composed of 171 Research Fronts. $RFII_{Ci}$ is equal to the sum of the two indicators $SCCoP_{Ci}$ and $SCCiP_{Ci}$.

$$\mathrm{RFII}_{Ci} = \mathrm{SCCoP}_{Ci} + \mathrm{SCCiP}_{Ci} = \sum_{k=1}^{10} \sum_{j=1}^{n} \frac{CoC_{ij}}{CoC_j} + \sum_{k=1}^{10} \sum_{j=1}^{n} \frac{CiC_{ij}}{CiC_j}$$

The formula for a country's Share of Citations to Core Papers in 11 broad research areas ($SCCoP_{Ci}$) is as follows:

$$\mathrm{SCCoP}_{Ci} = \sum_{k=1}^{10} \sum_{j=1}^{n} \frac{CoC_{ij}}{CoC_j}$$

The formula for a country's Share of Citations to Citing Papers in 11 broad research areas ($SCCiP_{Ci}$) is:

$$\mathrm{SCCiP}_{Ci} = \sum_{k=1}^{10} \sum_{j=1}^{n} \frac{CiC_{ij}}{CiC_j}$$

2. Analysis of the RLI_{Ci} of Top countries

We measured the RLIci of main countries for overall performance in 11 broad research areas comprising 171 Research Fronts and ranked the top countries. The following highlights are noted.

2.1 The USA remains the most active, China[1] is making rapid progress, and the gap in RLICi between the two nations is currently less than 10%

Based on 11 broad research areas and each country's respective performance in the 171 constituent Research Fronts, the USA is the most active, with an RLICi score of 209.23, ranking 1st (Figure 2). China ranks 2nd with a score of 191.43, and the gap with the USA is only 17.83, which has narrowed to less than 10%. The UK, Germany, and Italy score 85.59, 64.13, and 51.71, respectively, ranking 3rd, 4th, and 5th. The RLI_{Ci} scores for France, Australia, Canada, Spain, and the Netherlands register between 50 and 35, ranking those nations from 6th to 10th, with Japan (at 31.59) ranking 11th.

[1] In this report, data for China does not include that in Chinese Taiwan.

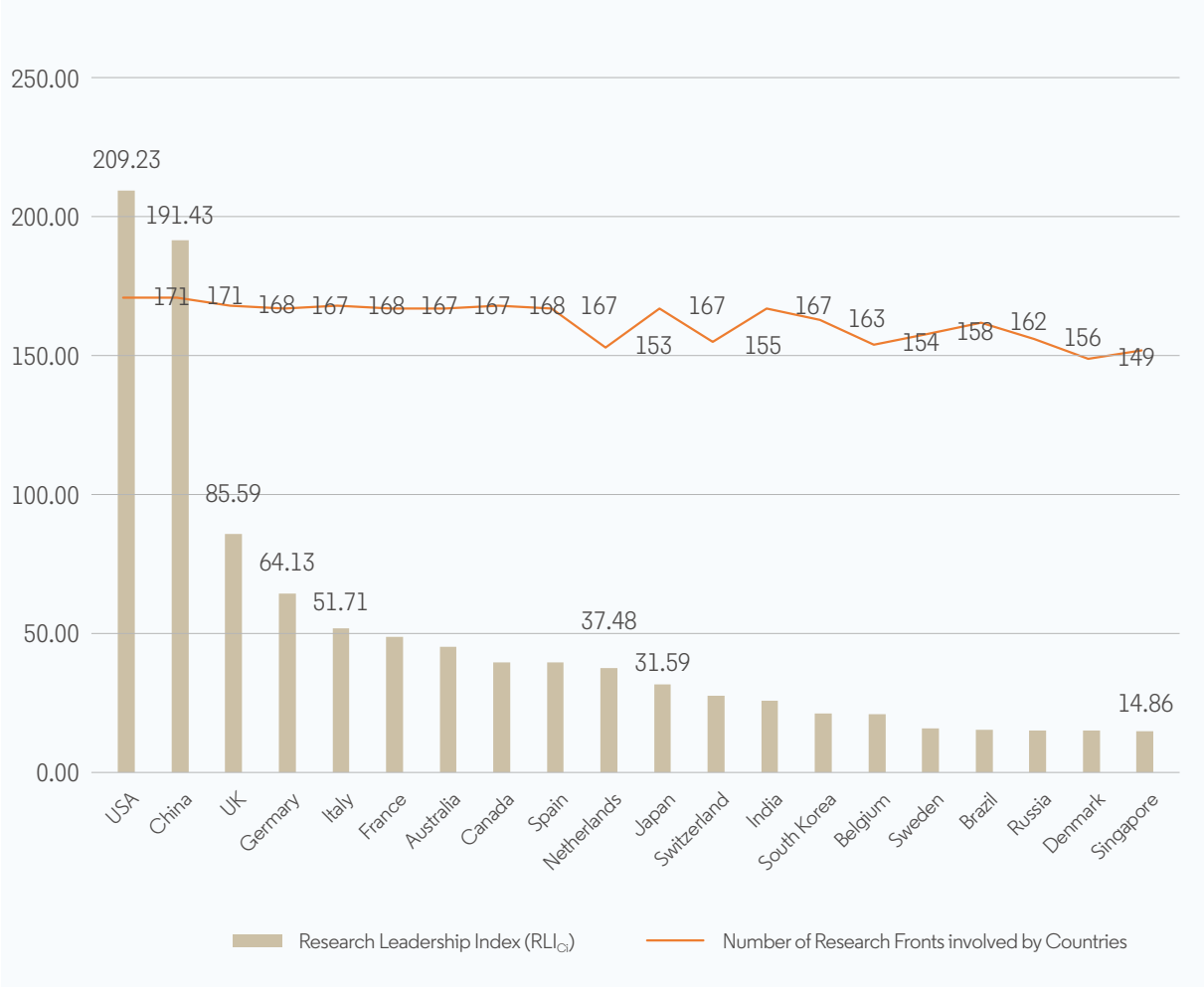


Figure 2. Research Leadership Index (RLI$_{Ci}$) of Top 20 Countries in 11 broad research areas with 171 Research Fronts

Table 1 shows that the rank order for the three indicators RLI$_{Ci}$, RFOI$_{Ci}$, and RFII$_{Ci}$ for the top seven countries is the same. For the remaining countries, scores on the three indicators do not differ widely, although precise calculation ranks the nations from 8th to 20th.

Table 1. The Research Leadership Index (RLI$_{Ci}$) of Top 20 Countries in 11 broad research areas with 171 Research Fronts

	RLI$_{Ci}$		RFOI$_{Ci}$		RFII$_{Ci}$	
	Score	Rank	Score	Rank	Score	Rank
USA	209.23	1	113.05	1	96.17	1
China	191.43	2	108.66	2	82.78	2

	RLI_{Ci}		$RFOI_{Ci}$		$RFII_{Ci}$	
	Score	Rank	Score	Rank	Score	Rank
UK	85.59	3	44.73	3	40.86	3
Germany	64.13	4	34.20	4	29.93	4
Italy	51.71	5	27.54	5	24.16	5
France	48.66	6	25.00	6	23.66	6
Australia	45.18	7	23.19	7	21.98	7
Canada	39.54	8	20.81	9	18.73	9
Spain	39.42	9	20.88	8	18.54	10
Netherlands	37.48	10	18.45	10	19.04	8
Japan	31.59	11	17.75	11	13.85	11
Switzerland	27.52	12	13.78	13	13.74	12
India	25.84	13	14.82	12	11.02	14
South Korea	21.23	14	11.91	14	9.32	15
Belgium	20.94	15	9.91	15	11.03	13
Sweden	15.76	16	7.90	18	7.86	16
Brazil	15.35	17	8.28	16	7.07	19
Russia	14.94	18	7.93	17	7.01	20
Denmark	14.92	19	7.73	19	7.20	18
Singapore	14.86	20	7.56	20	7.30	17

Table 2 compares the Research Leadership Index (RLI_{Ci}) of the USA, China, the UK, Germany, and France in 2017, 2018, 2019, 2020, and 2021, and the proportion relative to the USA From 2017 to 2020, the above five countries consistently ranked among the top five.

The USA scores 281.11, 227.39, 204.89, 226.63, and 209.23, respectively in the five years, maintaining 1st place. China ranks 2nd with 118.84, 118.38, 139.68, 151.29, and 191.43 points in five years, rising steadily, and the gap between China and the USA in RLI_{Ci} is gradually narrowing. The analysis also calculates the ratio of other countries to the USA at 100% per year. The ratio of China to the USA is 42.28%, 52.06%, 68.18%, 66.76%, and 91.50% for the five years. Thus, the proportion of China to the USA has increased significantly, especially in 2021, reaching 91.50% (a rise related to the surge of research on the COVID-19 epidemic), and the gap between the two countries has narrowed to less than 10%. Meanwhile, the UK, Germany, and France rank 3rd to 5th from 2017 to 2020, with little change compared with the USA However, in 2021, France fell to 6th and Italy won 5th.

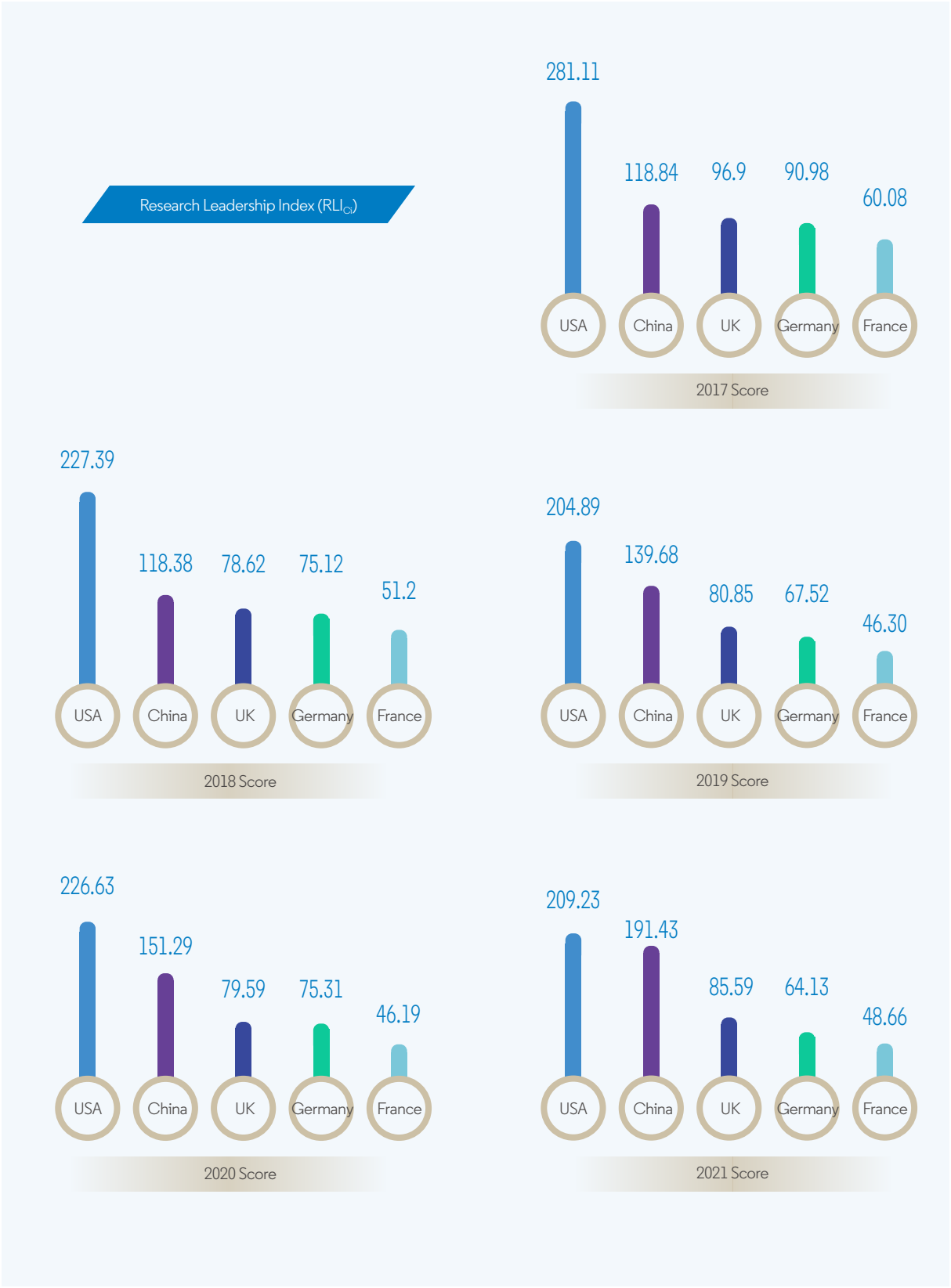

Research Leadership Index (RLI$_{Ci}$)
281.11
118.84
96.9
90.98
60.08
USA
China
UK
Germany
France
2017 Score
227.39
118.38
78.62
75.12
51.2
USA
China
UK
Germany
France
2018 Score
204.89
139.68
80.85
67.52
46.30
USA
China
UK
Germany
France
2019 Score
226.63
151.29
79.59
75.31
46.19
USA
China
UK
Germany
France
2020 Score
209.23
191.43
85.59
64.13
48.66
USA
China
UK
Germany
France
2021 Score

Table 2. Research Leadership Index (RLI_{Ci}) for Top 20 Countries in 11 broad research areas with 171 Research Fronts, for each of five years, 2017 to 2021

Indicators	Year	USA	China	UK	Germany	France
Research Leadership Index (RLI_{Ci}) Score	2017	281.11	118.84	96.90	90.98	60.08
	2018	227.39	118.38	78.62	75.12	51.20
	2019	204.89	139.68	80.85	67.52	46.30
	2020	226.63	151.29	79.59	75.31	46.19
	2021	209.23	191.43	85.59	64.13	48.66
%	2017	100.00%	42.28%	34.47%	32.36%	21.37%
	2018	100.00%	52.06%	34.57%	33.04%	22.52%
	2019	100.00%	68.18%	39.46%	32.95%	22.60%
	2020	100.00%	66.76%	34.95%	33.07%	20.29%
	2021	100.00%	91.50%	40.91%	30.65%	23.26%

2.2 The USA shows obvious strength in leading four areas, while China has outstanding performance in seven areas

For the 11 broad research areas, the USA's RLI_{Ci} scores are 1st in four of the main areas: "Geosciences", "Biological sciences", "Physics", and "Astronomy and astrophysics", and 2nd in the other seven areas. China ranks 1st in seven areas "Agricultural, plant and animal sciences", "Ecology and environmental sciences", "Clinical medicine", "Chemistry and materials science", "Mathematics", "Information science", and "Economics, psychology and other social sciences". China ranks 2nd in three areas: "Geosciences", "Biological sciences", and "Physics", while ranks 8th in "Astronomy and astrophysics".

Table 3. The score and rank of RLI_{Ci} and RLI_{Cik} of Top20 Countries

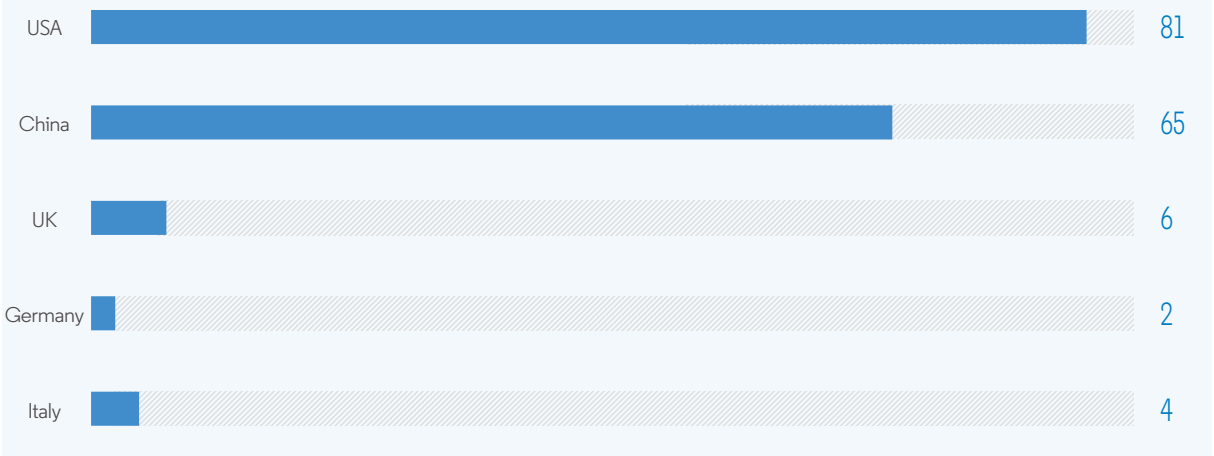
	11 broad research areas		Agricultural, plant and animal sciences		Ecology and environmental science		Geosciences		Clinical medicine		Biological science		Chemistry and materials science		Physics		Astronomy and astrophysics.		Mathematics		Information Science		Economics, psychology and other social sciences	
Countries	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
USA	209.23	1	13.82	2	13.31	2	21.47	1	44.03	2	30.68	1	7.01	2	15.43	1	25.59	1	10.91	2	9.49	2	17.48	2
China	191.43	2	18.34	1	15.11	1	11.29	2	45.32	1	16.05	2	24.80	1	9.19	2	7.77	8	15.90	1	9.78	1	17.88	1
UK	85.59	3	3.86	5	5.90	3	7.83	4	20.60	3	9.55	4	2.41	3	4.12	5	14.06	2	3.37	3	4.78	4	9.12	3
Germany	64.13	4	3.45	6	5.60	4	6.71	6	10.65	6	11.33	3	1.95	4	5.89	4	12.80	3	2.87	4	1.30	12	1.59	9
Italy	51.71	5	1.87	11	3.92	7	2.96	12	18.40	4	5.09	9	0.80	12	1.73	9	9.80	5	1.94	5	1.25	13	3.95	4
France	48.66	6	2.29	8	2.23	10	7.35	5	13.22	5	4.18	11	1.65	6	2.14	7	11.46	4	1.27	9	1.69	10	1.18	13
Australia	45.18	7	3.01	7	3.98	5	8.23	3	6.64	11	7.84	5	1.78	5	0.55	21	7.76	9	0.99	14	1.68	11	2.73	6
Canada	39.54	8	2.10	10	2.97	9	4.60	8	9.36	8	5.38	7	0.68	14	1.25	13	6.20	12	1.06	11	2.08	8	3.86	5
Spain	39.42	9	4.97	4	2.09	11	4.02	10	9.57	7	4.89	10	0.56	15	2.57	6	7.97	7	0.34	24	1.21	15	1.26	12
Netherlands	37.48	10	0.80	23	3.96	6	5.04	7	7.05	9	6.58	6	0.31	20	0.71	19	9.00	6	1.14	10	0.90	18	1.99	8
Japan	31.59	11	1.80	13	0.85	21	1.56	15	6.65	10	3.69	16	0.70	13	6.14	3	6.38	11	0.38	23	3.04	5	0.40	34
Switzerland	27.52	12	0.77	25	1.26	16	4.48	9	4.83	13	4.15	12	0.95	11	2.01	8	7.33	10	0.79	17	0.74	20	0.21	42
India	25.84	13	1.84	12	2.97	8	0.69	22	4.07	15	4.11	13	1.27	8	1.25	12	4.32	18	0.68	19	2.11	7	2.53	7
South Korea	21.23	14	1.55	14	0.41	32	0.99	19	4.11	14	5.22	8	1.07	9	1.33	11	3.49	21	1.27	8	1.23	14	0.57	28
Belgium	20.94	15	0.89	21	1.71	12	3.82	11	5.30	12	2.18	21	1.00	10	0.27	26	4.84	15	0.11	35	0.32	29	0.50	31
Sweden	15.76	16	0.78	24	1.32	15	1.38	17	1.65	27	3.91	14	0.16	26	0.76	18	3.60	20	0.59	21	0.16	39	1.44	10
Brazil	15.35	17	2.22	9	1.14	19	0.33	27	3.57	16	0.87	35	0.07	32	0.61	20	5.01	14	0.12	33	0.68	22	0.73	22
Russia	14.94	18	0.36	34	0.34	35	1.32	18	2.61	22	2.97	17	0.28	21	1.14	14	3.81	19	0.88	15	0.08	45	1.17	14
Denmark	14.92	19	0.39	33	1.61	13	1.42	16	2.81	19	3.87	15	0.04	41	0.17	31	3.26	24	0.08	41	0.52	24	0.73	21
Singapore	14.86	20	0.35	35	0.48	27	0.07	45	2.92	17	2.11	22	1.42	7	0.77	17	0.01	69	0.23	29	5.21	3	1.31	11

Among the 110 hot Research Fronts and 61 emerging Research Fronts in 11 broad research areas, the USA ranks 1st in 81, accounting for 47.37% of the171 Research Fronts. China earns the top spot in 65 fronts, or 38.01%. The UK is tops in six Research Fronts, Germany ranks 1st in two, while Italy can claim the top ranking in four fronts (Table 4). The USA and China account for about 85% of the 171 fronts while the UK and Germany together account for about 5%, and the other 10% is shared by 10 countries.

Of the 11 broad research areas, there are 10 fronts within "Chemistry and materials science" in which China ranks 1st, compared to only one for the USA, showing China's absolute advantage in this area.

In the six main areas of "Agricultural, plant and animal sciences", "Ecology and environmental sciences", "Clinical medicine", "Mathematics", "Information science", and "Economics, psychology and other social sciences", the number of fronts in which China ranks 1st is equal to or higher than that of the USA as most of the research fronts are COVID-19 related topics in "Clinical medicine", and scientists in China have made outstanding contributions in fighting COVID-19, China has demonstrated remarkable progress in this area.

In the three main areas of "Geosciences", "Biological sciences" and "Physics", the number of fronts in which China ranks 1st is less than that of the USA Among the 12 fronts in "Astronomy and astrophysics", the USA ranks 1st in 10, while China has none (Table 4). This relative gap is unlikely to narrow in the short term.

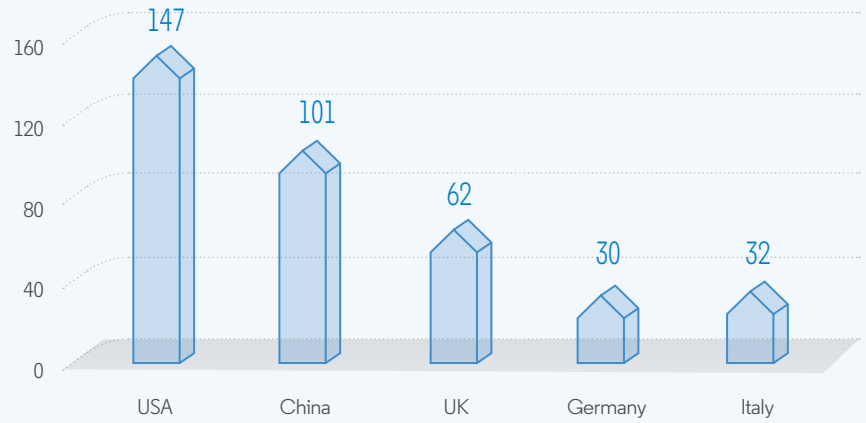


Numbers of ranking 1st RFs based on RLI_{Ci}

Table 4. The numbers and ratios of the Research Fronts in which the respective Top 5 countries rank first, out of 171 fronts in 11 broad research areas (based on RLI_{Ci})

Areas	Numbers of RFs	Numbers of ranking 1st RFs					Ratios				
		USA	China	UK	Germany	Italy	USA	China	UK	Germany	Italy
11 broad research areas total	171	81	65	6	2	4	47.37%	38.01%	3.51%	1.17%	2.34%
Agricultural, plant and animal sciences	14	5	6	1	0	0	35.71%	42.86%	7.14%	0.00%	0.00%
Ecology and environmental sciences	12	5	5	0	1	1	41.67%	41.67%	0.00%	8.33%	8.33%
Geosciences	11	9	2	0	0	0	81.82%	18.18%	0.00%	0.00%	0.00%
Clinical medicine	39	18	16	1	0	1	46.15%	41.03%	2.56%	0.00%	2.56%
Biological sciences	21	13	5	0	0	0	61.90%	23.81%	0.00%	0.00%	0.00%
Chemistry and materials science	13	1	10	1	0	0	7.69%	76.92%	7.69%	0.00%	0.00%
Physics	11	7	3	1	0	0	63.64%	27.27%	9.09%	0.00%	0.00%
Astronomy and astrophysics	12	10	0	0	1	0	83.33%	0.00%	0.00%	8.33%	0.00%
Mathematics	10	4	5	0	0	1	40.00%	50.00%	0.00%	0.00%	10.00%
Information Science	11	2	5	1	0	0	18.18%	45.45%	9.09%	0.00%	0.00%
Economics, psychology and other social sciences	17	7	8	1	0	1	41.18%	47.06%	5.88%	0.00%	5.88%

Among nations ranking among the top three performers in the 171 Research Fronts (Table 5), the USA earns that distinction in 147 fronts, or 85.96%, China in 101 Research Fronts (59.06%), the UK in 62, Germany in 30, and Italy in 32, with the latter three countries able to boast the achievement in 36.26%, 17.54%, and 18.71% of the total number of Research Fronts.



Numbers of ranking Top three RFs based on RLI_{Ci}

Table 5. The numbers and ratios of nations ranking among the top three performers in Research Fronts, among the Top 5 countries in 11 broad research areas with 171 Research Fronts (based on RLI_{Ci})

Areas	Numbers of RFs	Numbers of ranking Top three RFs					Ratios				
		USA	China	UK	Germany	Italy	USA	China	UK	Germany	Italy
11 broad research areas total	171	147	101	62	30	32	85.96%	59.06%	36.26%	17.54%	18.71%
Agricultural, plant and animal sciences	14	9	10	5	2	1	64.29%	71.43%	35.71%	14.29%	7.14%
Ecology and environmental sciences	12	10	9	4	4	1	83.33%	75.00%	33.33%	33.33%	8.33%
Geosciences	11	11	4	4	1	1	100.00%	36.36%	36.36%	9.09%	9.09%
Clinical medicine	39	36	26	13	2	22	92.31%	66.67%	33.33%	5.13%	56.41%
Biological sciences	21	20	10	5	5	1	95.24%	47.62%	23.81%	23.81%	4.76%
Chemistry and materials science	13	11	11	4	3	1	84.62%	84.62%	30.77%	23.08%	7.69%

Areas	Numbers of RFs	Numbers of ranking Top three RFs					Ratios				
		USA	China	UK	Germany	Italy	USA	China	UK	Germany	Italy
Physics	11	11	6	2	4	1	100.00%	54.55%	18.18%	36.36%	9.09%
Astronomy and astrophysics	12	12	0	9	7	2	100.00%	0.00%	75.00%	58.33%	16.67%
Mathematics	10	7	8	3	2	1	70.00%	80.00%	30.00%	20.00%	10.00%
Information Science	11	8	8	3	0	0	72.73%	72.73%	27.27%	0.00%	0.00%
Economics, psychology and other social sciences	17	12	9	10	0	1	70.59%	52.94%	58.82%	0.00%	5.88%

The USA makes the top three in more than 60% of the respective Research Fronts associated with each of the 11 broad research areas. That means the USA maintains a leading position in all areas. In the three areas of "Astronomy and astrophysics", "Geosciences", and "Physics", the USA ranks among the top three performers in 100% of the pertinent Research Fronts. This notably superior performance also carries over into "Clinical medicine" and "Biological sciences", all the two areas in which the USA ranks among the top three in 95.24% and 92.31% respectively. The lowest proportion for the USA is in the area of "Agricultural, plant and animal sciences", accounting for 64.29%. n the other five areas, meanwhile, the USA's proportions of top three account range from 70.00% to 84.62%.

China's proportion of top-three placements ratio reaches more than 60% in six major specialty areas, of which the highest proportion is in "Chemistry and material science", accounting for 84.62%. China registers among the top three in the range of 70% to 80% in "Agricultural, plant and animal sciences", "Information science", "Ecology and environmental sciences", and "Mathematics". China's proportion of top three placements in "Clinical medicine" has also increased from 16.67% in 2020 to 66.67% in 2021. In the area of "Biological Sciences", "Economics, psychology and other social sciences", as well as "Physics", the proportion of top-three placements ratio registers at 47.62%, 52.94%, and 54.55% respectively, accounting for about half. China's ratio of top three fronts in the area of "Geosciences" is 36.36%, while the country does not rank among the top three in the area of "Astronomy and astrophysics".

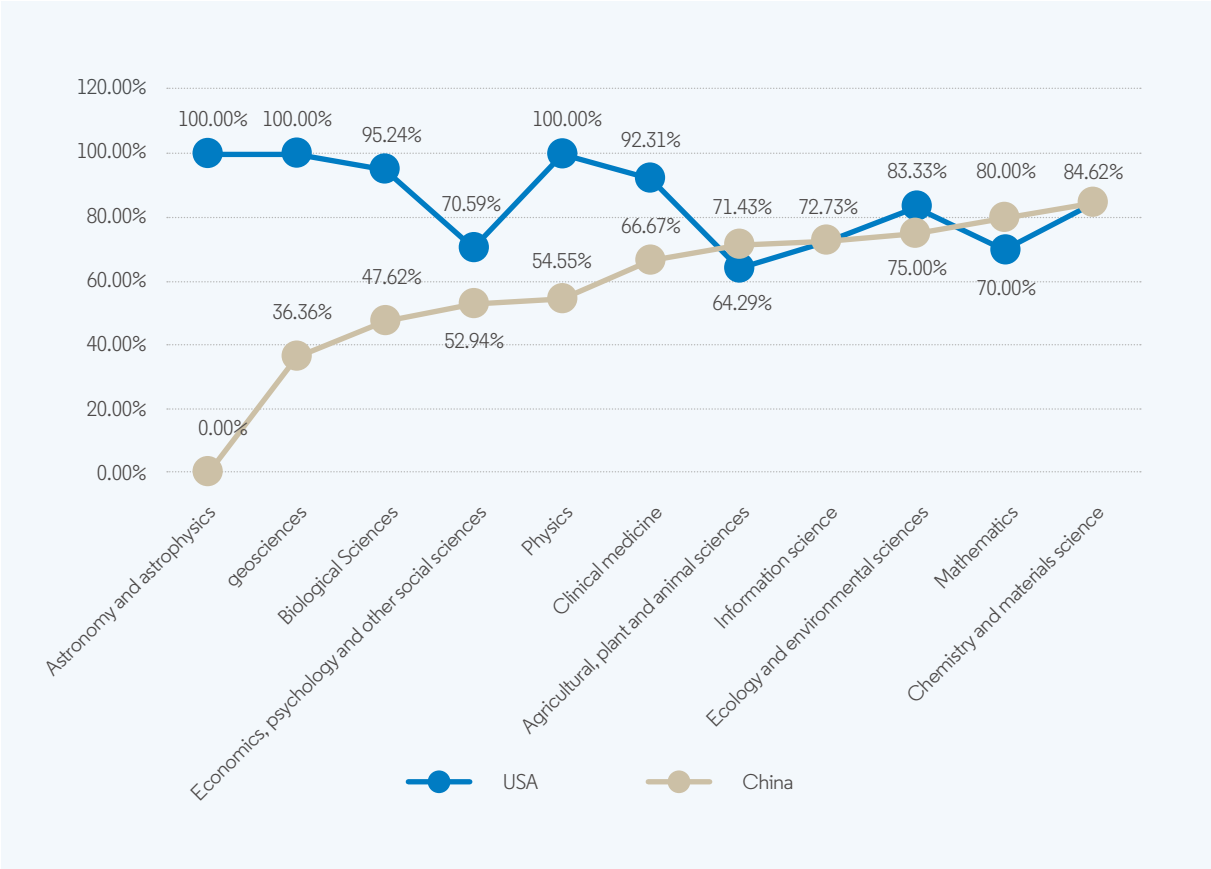


Figure 3. The ratios of the ranking Top three Research Fronts for China and USA in 11 broad research areas with 171 Research Fronts (based on RLI_{Ci})

The UK, meanwhile, performs notably in two main areas: "Astronomy and astrophysics", registering among the top three in 75% of the Research Fronts in that broad specialty area, and in "Economics, psychology and other social sciences" (nearly 60% of the fronts). In the other nine areas, the UK's presence in the top three ranges from 18.18% to 36.36% of Research Fronts.

Germany has its highest proportion of top three Research Fronts in the area of "Astronomy and astrophysics", accounting for nearly 60.00%, representing the nation's dominant performance. Germany ranks in the top three in between 20.00% and 36.36% of Research Fronts in the five areas of "Biological Sciences", "Physics", "Ecology and environmental sciences", "Mathematics", and "Chemistry and materials science". In the other five areas, Germany accounts for less than 20% of fronts, with its top three performances in those areas registering at between 5.13% and 14.29% in "Geosciences", "Clinical medicine", and "Agricultural, plant and animal sciences". Germany, meanwhile, does not rank in the top three in the areas of "Economics, psychology and other social sciences" and "Information science".

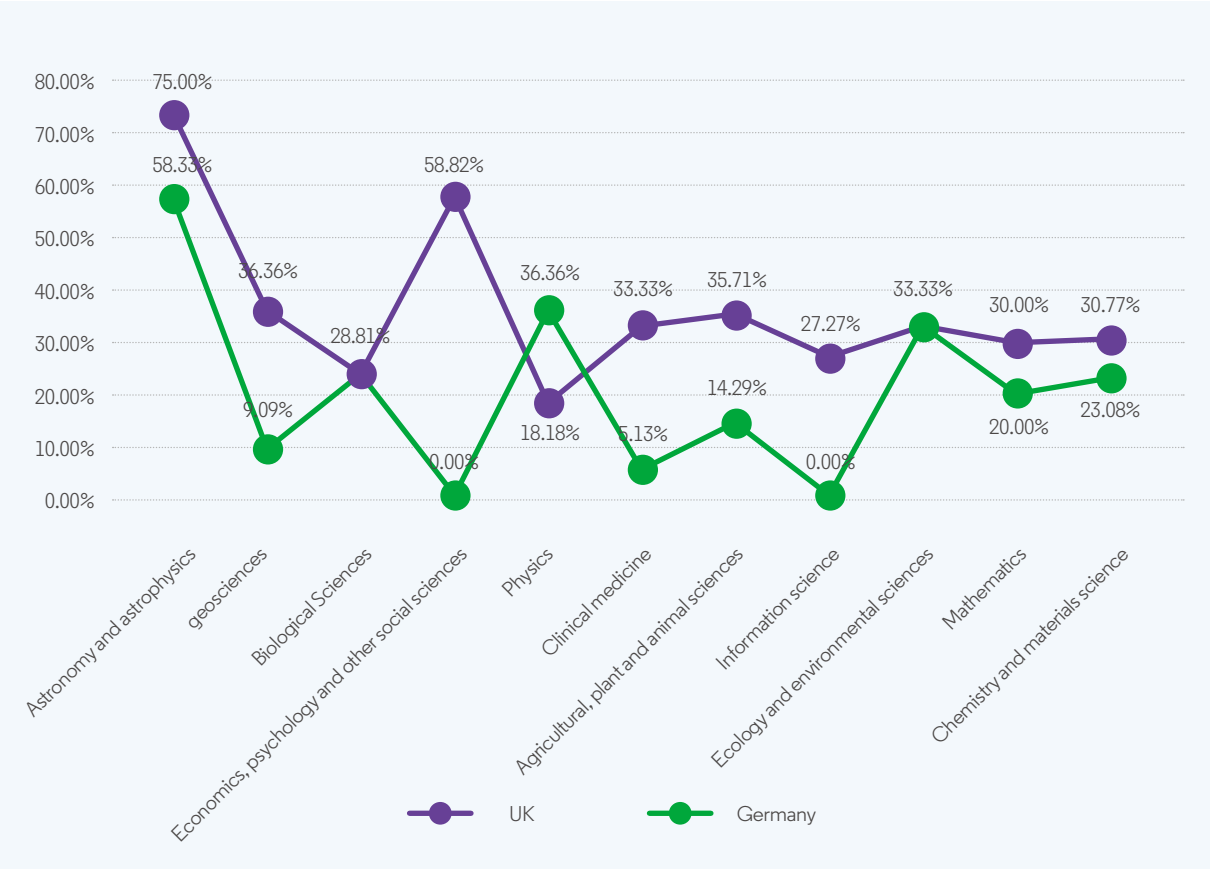


Figure 4. The ratios of Research Fronts in which the UK and Germany rank among the top three performers, in 11 broad research areas comprising 171 Research Fronts (based on RLI_{Ci})

3. Analysis of the Research Leadership Index (RLI_{Cik}) of countries in different areas

This section highlights the scores and rankings obtained via the RLI_{Cik} measurement, exploring the Research Front activity and influence of various countries in specific areas, and analyzing the respective sources of national vitality in scientific and technical innovation.

3.1 AGRICULTURAL, PLANT AND ANIMAL SCIENCES: China boost to 1st; the USA is 2nd; Pakistan, Spain, and the UK are the 3rd, 4th, and 5th

In the area of "Agricultural, plant and animal sciences", China is the most active according to its RLI_{Cik} score of 18.34, ranking 1st (Table 6). The USA scores 13.82, ranking 2nd. Pakistan scores close to Spain and Britain, ranking 3rd, 4th, and 5th, respectively. As can be seen from Table 6, the ranking according to $RFII_{Cik}$ and $RFOI_{Cik}$ is the same as RLI_{Cik} for China and the USA. By contrast, the rankings for Pakistan, Spain and the UK vary slightly according to the three indicators.

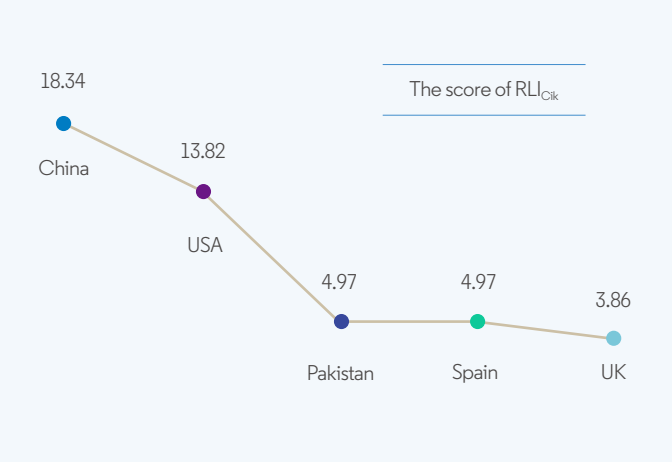


Table 6. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Agricultural, plant and animal sciences"

Indicators	Score					Rank				
	China	USA	Pakistan	Spain	UK	China	USA	Pakistan	Spain	UK
RLI_{Cik}	18.34	13.82	4.97✶	4.97✶	3.86	1	2	3	4	5
$RFOI_{Cik}$	10.72	7.19	2.83	2.59	1.96	1	2	3	4	6
$RFII_{Cik}$	7.62	6.63	2.14	2.37	1.89	1	2	4	3	5

✶Note: the scores for Pakistan and Spain have been rounded to 4.97, although their respective full scores were actually 4.9715 and 4.9655, hence the difference in their ranking.

3.2 ECOLOGY AND ENVIRONMENTAL SCIENCES: China is in the leading position; the USA is 2nd; with the UK, Germany, and Australia ranking 3rd, 4th, and 5th

In the area of "Ecology and environmental sciences" (Table 7), China scores 15.11 in RLICik, ranking 1st, demonstrating the most activity. The USA scores 13.31, ranking 2nd. In third and fourth place are the UK and Germany, with the score of 5.90 and 5.60, significantly lower than the top two. Australia scores 3.98, ranking 5th.

The rank order of the USA and China remains the same for all three indicators: RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$. Meanwhile, the rankings of the $RFOI_{Cik}$ indicator for the UK, Germany, and Australia fluctuate somewhat compared to the other two measures.

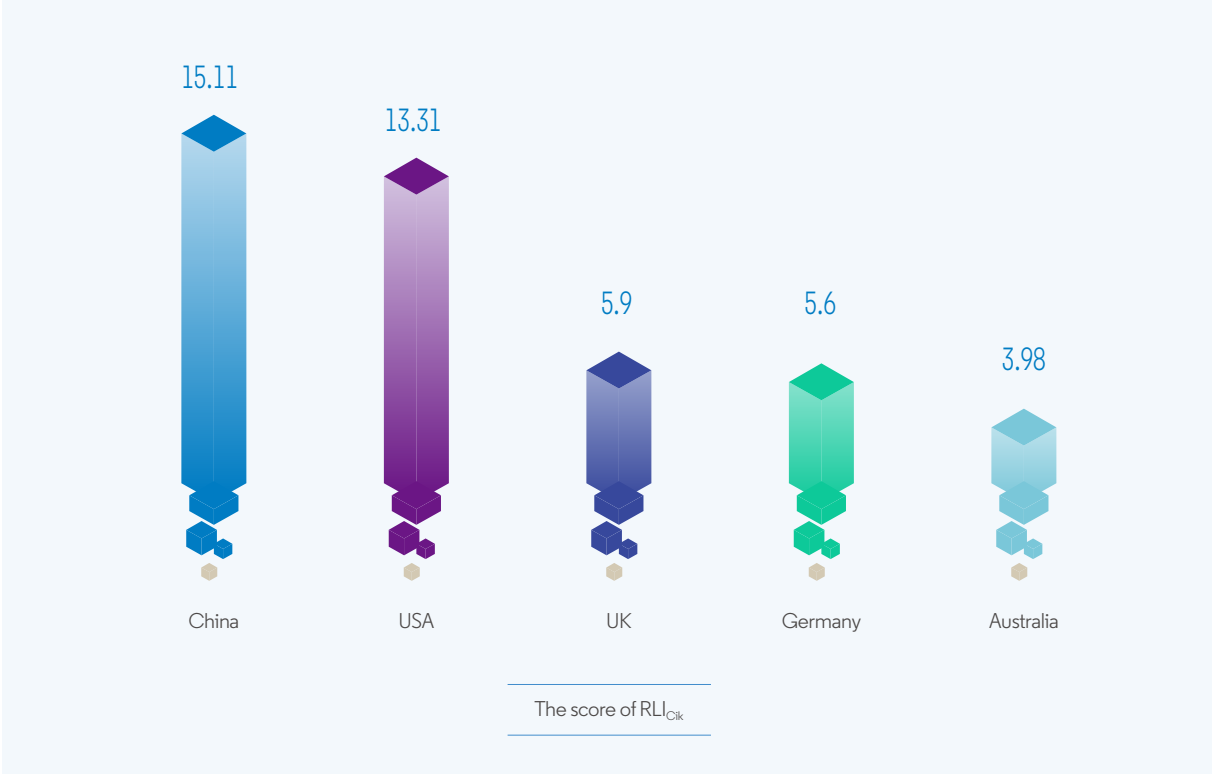


Table 7. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Ecology and environmental sciences"

Indicators	Score					Rank				
	China	USA	UK	Germany	Australia	China	USA	UK	Germany	Australia
RLI_{Cik}	15.11	13.31	5.90	5.60	3.98	1	2	3	4	5
$RFOI_{Cik}$	8.21	7.33	2.95	2.96	1.75	1	2	4	3	6
$RFII_{Cik}$	6.90	5.98	2.95	2.64	2.23	1	2	3	4	6

3.3 Geosciences: The USA is the most active; China is 2nd; Australia, the UK, and France are 2nd-5th

In the area of "Geosciences", the USA scores 21.47 in RLI_{Cik}, ranking 1st, far ahead of other countries. China ranks 2nd with a score of 11.29, about half that of the USA Australia, the UK, and France score 8.23, 7.83, and 7.35 respectively, ranking 3rd to 5th respectively. As can be seen in Table 8, the five countries rank in the same order according to all three indicators.

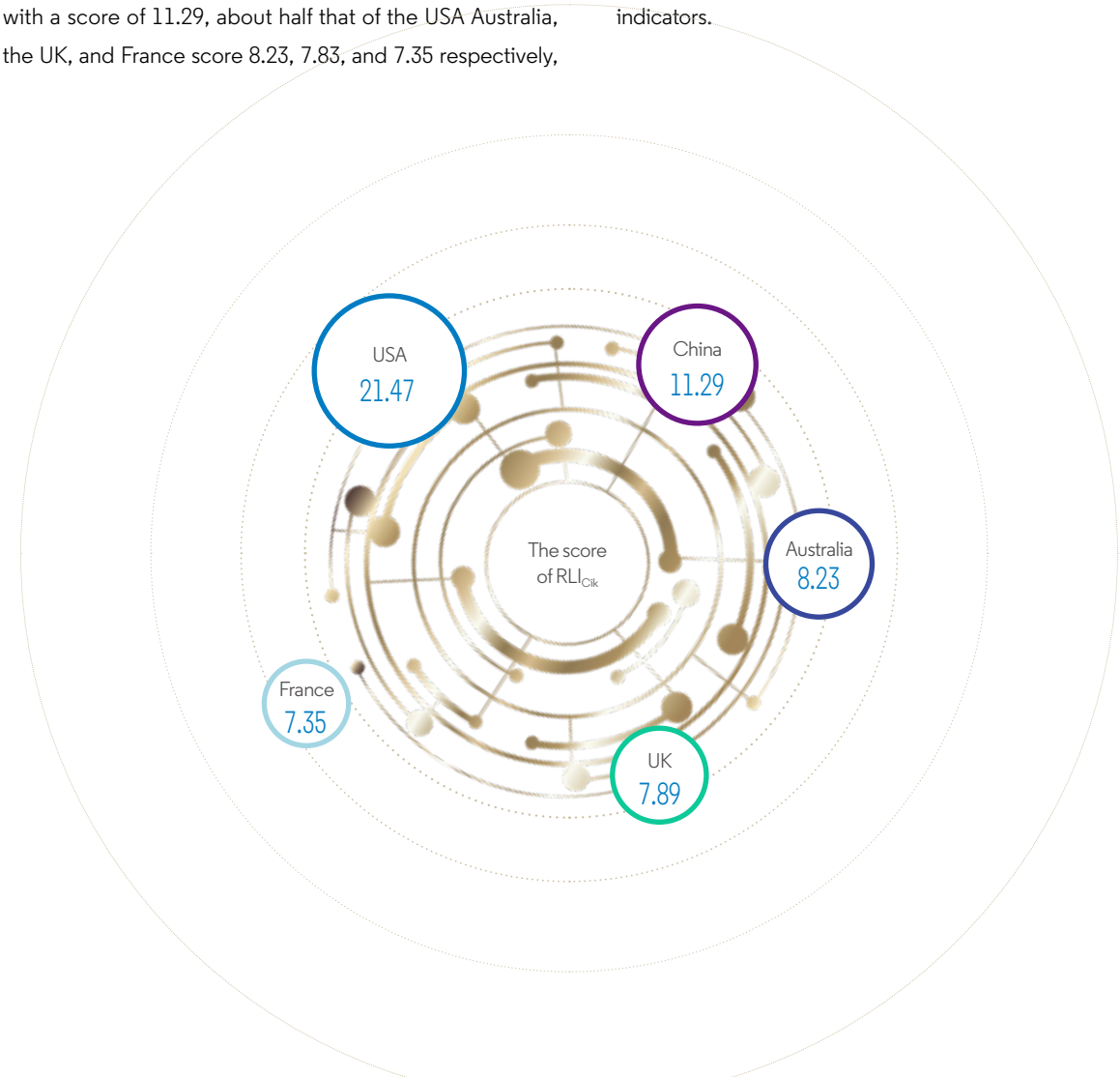


Table 8. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Geosciences"

Indicators	Score					Rank				
	USA	China	Australia	UK	France	USA	China	Australia	UK	France
RLI_{Cik}	21.47	11.29	8.23	7.83	7.35	1	2	3	4	5
$RFOI_{Cik}$	11.70	6.57	4.34	4.19	3.83	1	2	3	4	5
$RFII_{Cik}$	9.78	4.72	3.88	3.64	3.51	1	2	3	4	5

3.4 CLINICAL MEDICINE: China is equivalent to the USA, the UK and Italy have close scores, and France ranks 5th

In the area of "Clinical medicine", China and the USA score 45.32 and 44.03 in RLI_{Cik}, respectively, ranking 1st and 2nd, far ahead of other countries. In 2020, China ranked 12th in the area of "Clinical medicine". This year, the Research Fronts related to COVID-19 account for nearly 90% (35/39). Chinese scientists have been particularly prominent in fighting the COVID-19 epidemic, notably in first identifying the COVID-19 pathogen as SARS-CoV-2, and subsequently being the first publish the virus's complete genome sequence. Their works are of great significance to the future global epidemic prevention and vaccine and drug research and development. China's contributions are well demonstrated in the analysis of research leadership index.

Elsewhere in Table 9, the UK and Germany register at 20.60 and 18.40 respectively, ranking 3th and 4th. France scores 13.22, ranking 5th, with a significant gap with Top 4 countries.

China's placements vary slightly according to the three indicators: the country ranks the 1th in RLI_{Cik} and $RFII_{Cik}$, 2nd in $RFOI_{Cik}$. The respective rankings of the UK, Italy and France in RLI_{Cik} are identical to those in $RFOI_{Cik}$ and $RFII_{Cik}$.

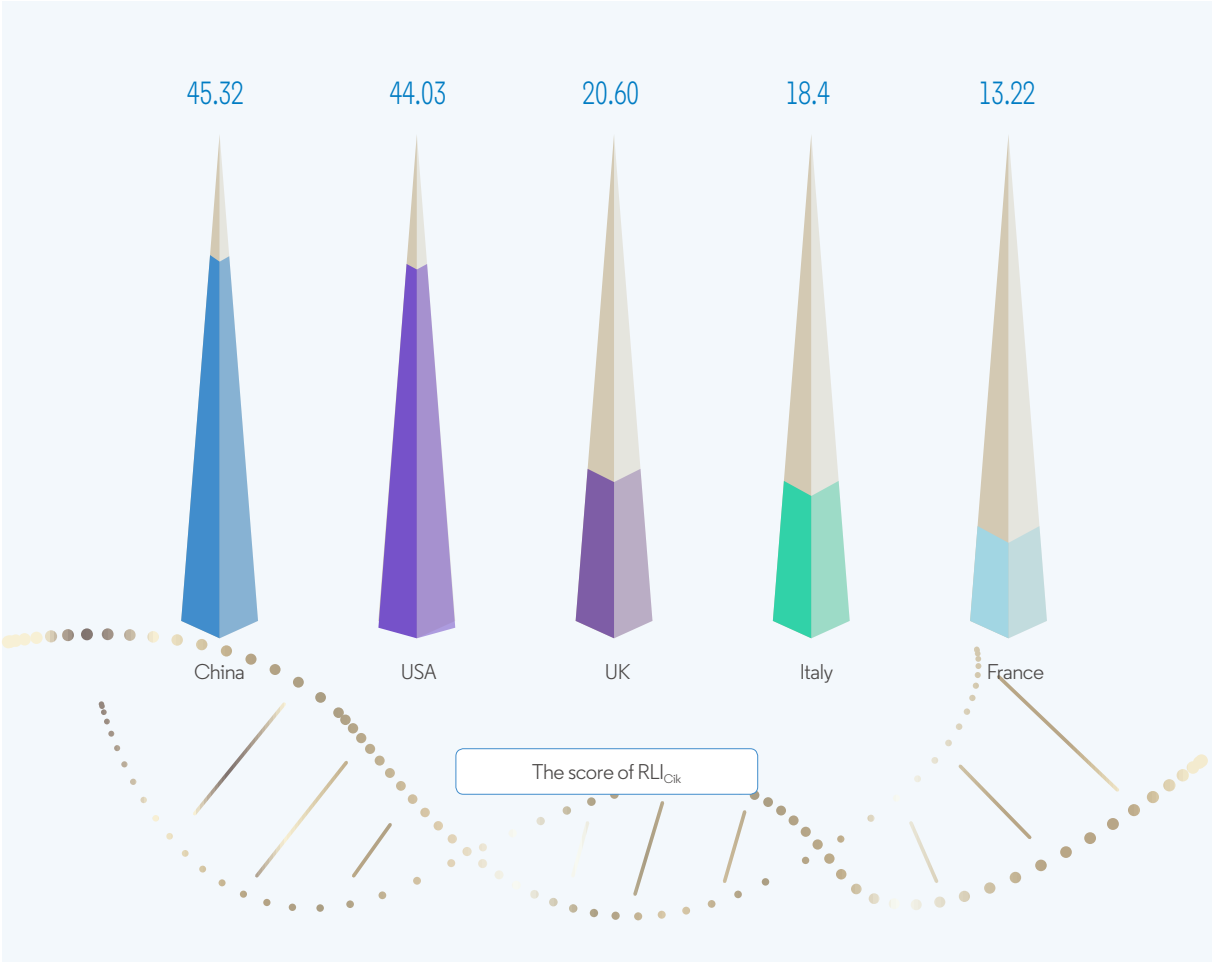


Table 9. The score and rank of Top 5 countries based on RLI$_{Cik}$, RFOI$_{Cik}$ and RFII$_{Cik}$ in the area of "Clinical medicine"

Indicators	Score					Rank				
	China	USA	UK	Italy	France	China	USA	UK	Italy	France
RLI$_{Cik}$	45.32	44.03	20.60	18.40	13.22	1	2	3	4	5
RFOI$_{Cik}$	22.57	22.78	10.36	9.84	6.44	2	1	3	4	5
RFII$_{Cik}$	22.74	21.25	10.24	8.56	6.78	1	2	3	4	5

3.5 BIOLOGICAL SCIENCES: The USA leads substantially, China is 2nd, and Germany, the UK, and Australia rank 3rd to 5th

In the area of "Biological sciences", the USA registers at 30.68 in RLI_{Cik}, placing 1st, with a score roughly twice that of China (16.05). Germany, the UK, and Australia score 11.33, 9.55 and 7.84 respectively, ranking 3rd, 4th, and 5th. The Top 5 countries maintain the same rank order according to the three indicators.

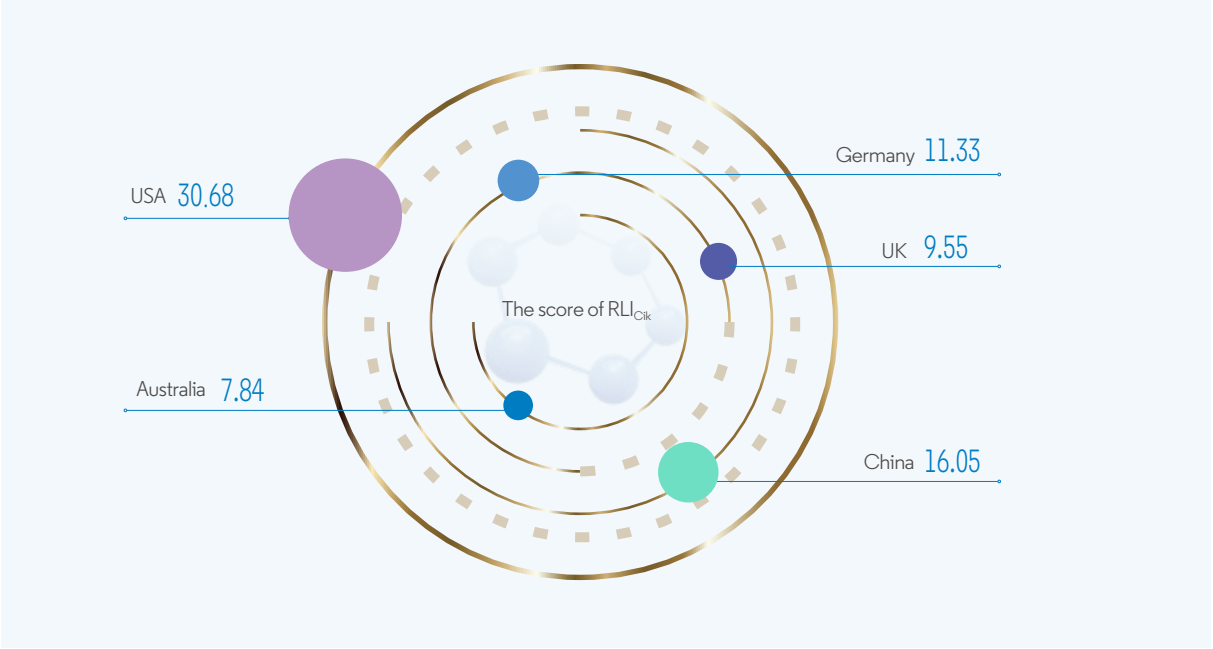


Table 10. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Biological sciences"

Indicators	Score					Rank				
	USA	China	Germany	UK	Australia	USA	China	Germany	UK	Australia
RLI_{Cik}	30.68	16.05	11.33	9.55	7.84	1	2	3	4	5
RFOICik	16.76	8.50	5.65	5.42	4.00	1	2	3	4	5
RFIICik	13.92	7.55	5.68	4.13	3.84	1	2	3	4	5

3.6 CHEMISTRY AND MATERIALS SCIENCE: China's RLI_{Cik} is 3.5 times that of the USA; the UK, Germany, and Australia rank 3rd to 5th

In the area of "Chemistry and materials science", China's RLI_{Cik} score is 24.80, 3.5 times that of the USA, earning China 1st place (Table 11). The USA scores 7.01, ranking 2nd. These scores indicate a significant activity gap between the USA and China in this area. Although the USA lags China by a large margin, it still far exceeds other countries. The UK, Germany, and Australia post marks of 2.41, 1.95, and 1.78 respectively, ranking 3rd to 5th. The rankings based on the indicators RLI_{Cik}, $RFOI_{Cik}$, and $RFII_{Cik}$ for China and the USA are exactly the same, while the rankings of the UK, Germany and Australia vary slightly among the three indicators.

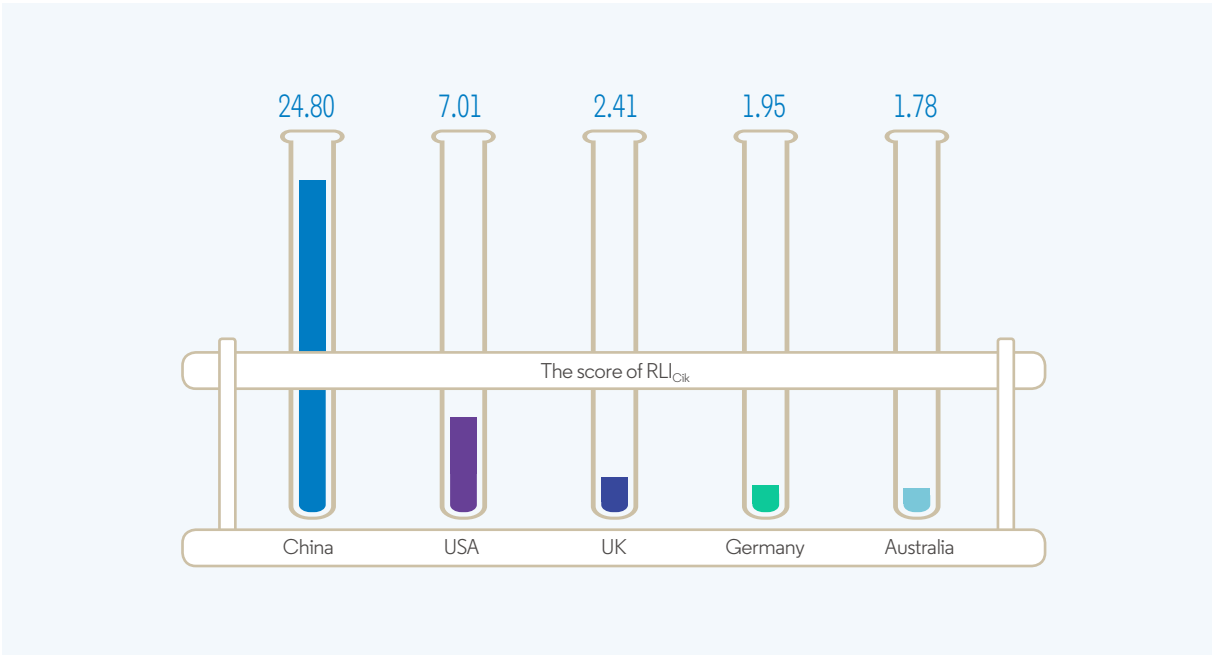


Table 11. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Chemistry and materials science"

Indicators	Score					Rank				
	China	USA	UK	Germany	Australia	China	USA	UK	Germany	Australia
RLI_{Cik}	24.80	7.01	2.41	1.95	1.78	1	2	3	4	5
$RFOI_{Cik}$	15.74	3.77	1.10	1.21	0.96	1	2	4	3	5
$RFII_{Cik}$	9.06	3.25	1.31	0.74	0.82	1	2	3	5	4

3.7 PHYSICS: The USA leads in all areas; China is 2nd, Japan, Germany, and the UK are 3rd, 4th, and 5th

In the area of "Physics", the USA posts the highest degree of activity with an RLI_{Cik} of 15.43, showing an overall leading trend. China scores 9.19, ranking 2nd. while Japan and Germany score close at 6.14 and 5.89, respectively. The UK scores 4.12, ranking in 5th place.

The USA, China, and the UK rank the same across all three indicators, while, for Japan and Germany, the rankings based on the $RFOI_{Cik}$ indicator display some variance.

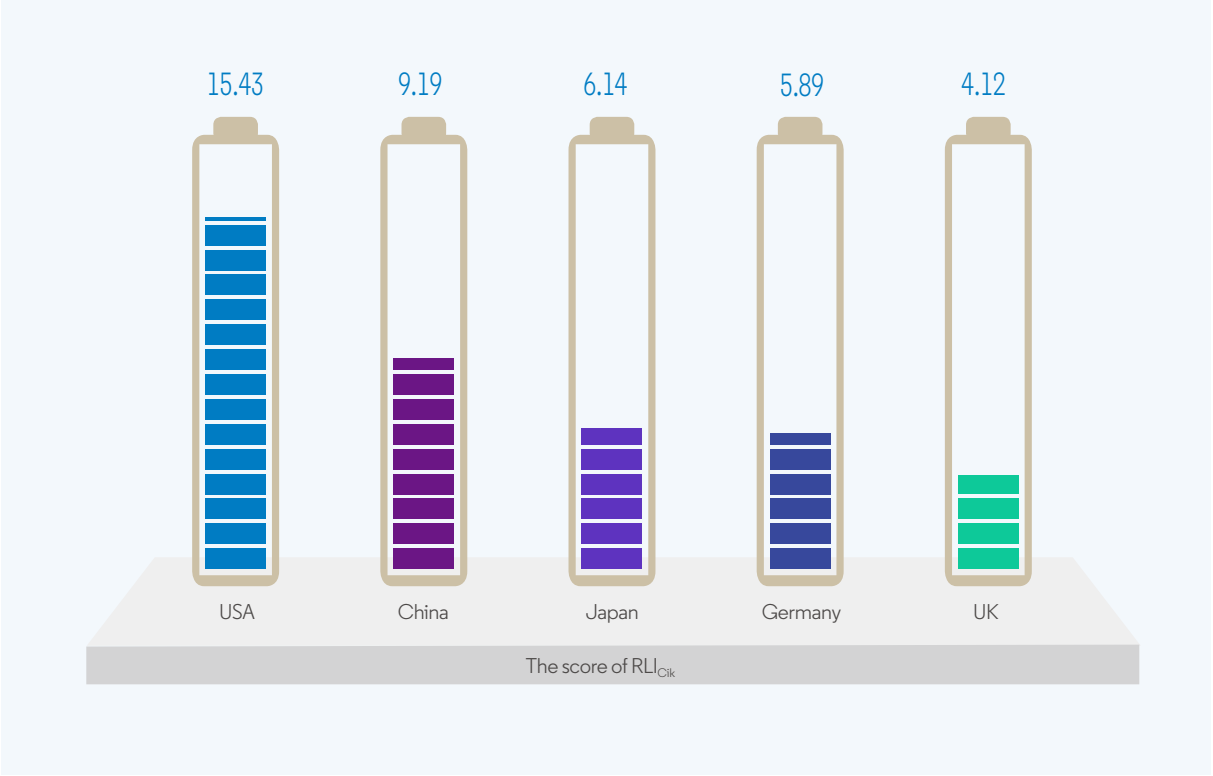


Table 12. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Physics"

Indicators	Score					Rank				
	USA	China	Japan	Germany	UK	USA	China	Japan	Germany	UK
RLI_{Cik}	15.43	9.19	6.14	5.89	4.12	1	2	3	4	5
$RFOI_{Cik}$	8.47	6.16	3.63	3.22	2.36	1	2	3	4	5
$RFII_{Cik}$	6.96	3.03	2.51	2.67	1.76	1	2	4	3	5

3.8 ASTRONOMY AND ASTROPHYSICS: The USA has a dominant position; the UK, Germany, France, and Italy rank 2nd to 5th; and China ranks 8th

In the area of "Astronomy and astrophysics" (Table 13), the USA ranks 1st, with an RLI_{Cik} score of 25.59. The UK ranks 2nd with a mark of 14.06, with Germany 3rd at 12.80, followed by France (11.46) and Italy (9.80). China places 8th with a score of 7.77, the same as last year. The Top 5 countries rank in the same order on the three indicators, while China's placements vary according to the different measures.

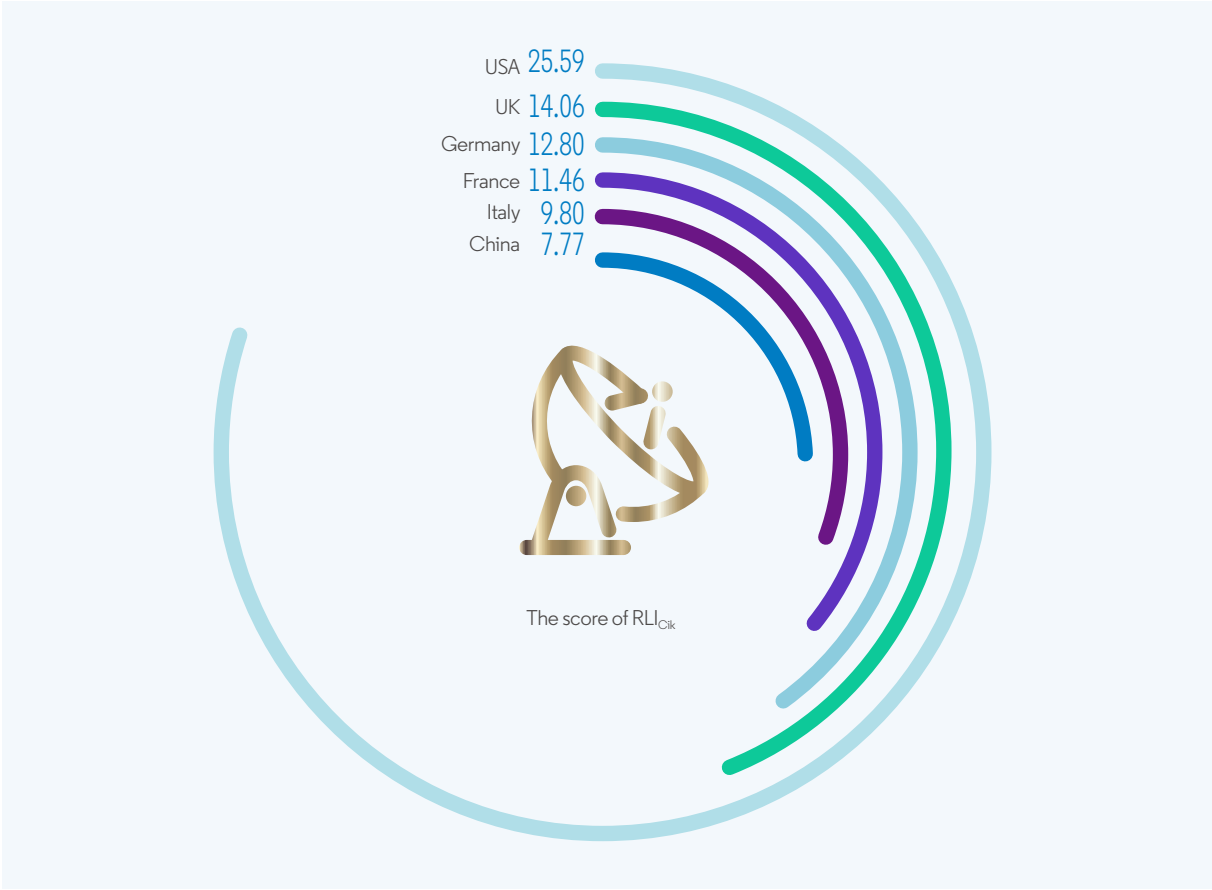


Table 13. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Astronomy and astrophysics"

Indicators	Score						Rank					
	USA	UK	Germany	France	Italy	China	USA	UK	Germany	France	Italy	China
RLI_{Cik}	25.59	14.06	12.80	11.46	9.80	7.77	1	2	3	4	5	8
$RFOI_{Cik}$	14.55	7.58	6.90	5.90	5.19	4.17	1	2	3	4	5	7
$RFII_{Cik}$	11.04	6.49	5.89	5.55	4.61	3.60	1	2	3	4	5	10

3.9 MATHEMATICS: China is the most active, the USA is 2nd, while the UK, Germany, and Italy are 3rd to 5th

In the area of "Mathematics", China achieves the most active performance and ranks 1st, with a score of 15.90. Meanwhile, the USA posts a score of 10.91, ranking 2nd. China and the USA are ahead of other countries. The UK, Germany, and Italy score 3.37, 2.87, and 1.94 respectively, ranking 3rd to 5th.

The rankings of the top four countries according to the three indicators are completely consistent, while Italy's ranking according to the $RFOI_{Cik}$ indicator is different from the other two measures.

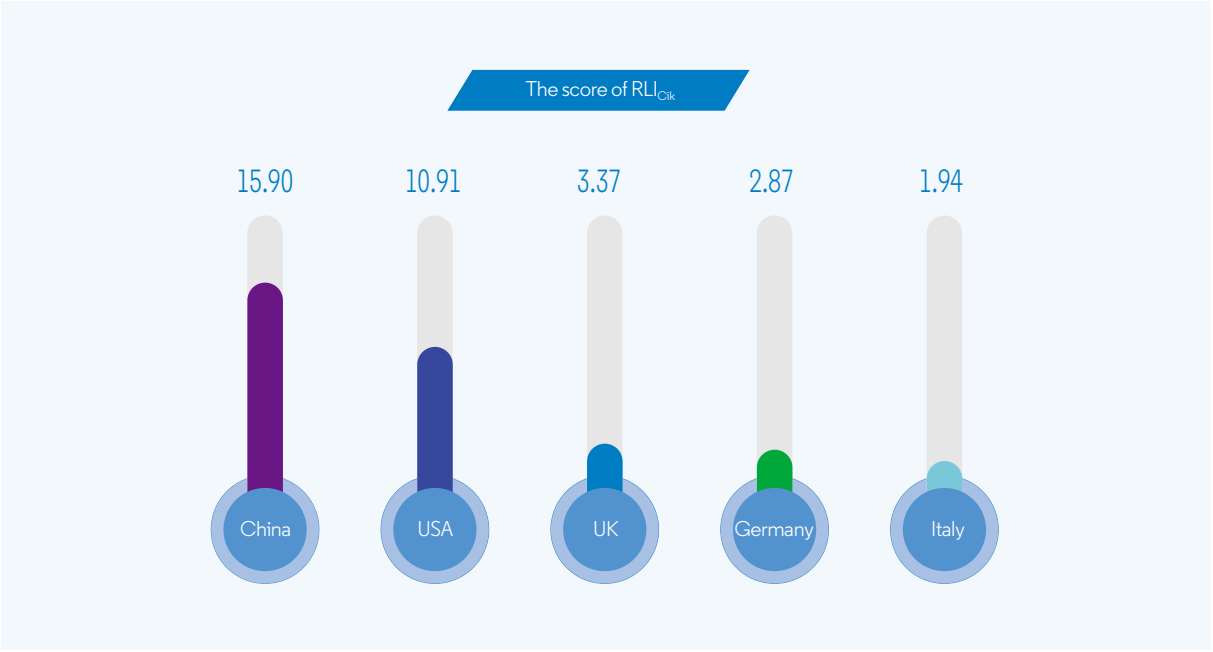


Table 14. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Mathematics"

Indicators	Score					Rank				
	China	USA	UK	Germany	Italy	China	USA	UK	Germany	Italy
RLI_{Cik}	15.90	10.91	3.37	2.87	1.94	1	2	3	4	5
$RFOI_{Cik}$	9.75	5.90	1.94	1.54	1.06	1	2	3	4	6
$RFII_{Cik}$	6.15	5.01	1.43	1.33	0.87	1	2	3	4	5

3.10 INFORMATION SCIENCE: China and the USA are the most active, Singapore, the UK, and Japan rank 3rd to 5th

In this area of "Information science", China and the USA are the most active, with respective RLI_{Cik} scores of 9.78 and 9.49. Singapore, the UK, and Japan score 5.21, 4.78, and 3.04, ranking 3rd to 5th, respectively. The rankings based on the three indicators for the top 5 countries tend to vary.

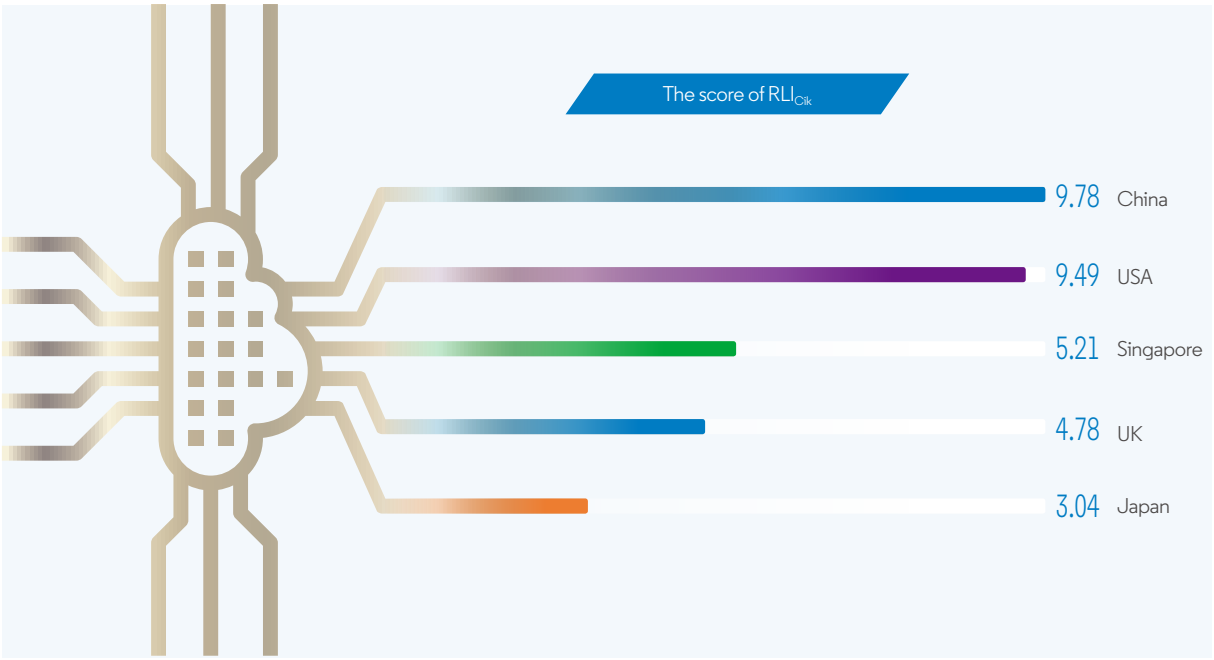


Table 15. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Information science"

Indicators	Score					Rank				
	China	USA	Singapore	UK	Japan	China	USA	Singapore	UK	Japan
RLI_{Cik}	9.78	9.49	5.21	4.78	3.04	1	2	3	4	5
$RFOI_{Cik}$	6.47	5.39	2.50	2.56	1.31	1	2	4	3	6
$RFII_{Cik}$	3.32	4.10	2.70	2.22	1.73	2	1	3	4	5

3.11 ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES: The scores of China and the USA are close; the UK, Italy, and Canada rank 3rd to 5th

In this area of "Economics, psychology and other social sciences", the RLI_{Cik} scores of China and the USA are very close, at 17.88 and 17.48, respectively. The UK scores 9.12, ranking 3rd. Italy and Canada rank 4th and 5th with 3.95 and 3.86, respectively. For the UK, the rankings based on the indicators RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ are the same across the board, contrasting with the varying placements by China, the USA, Italy, and Canada according to the three measures.

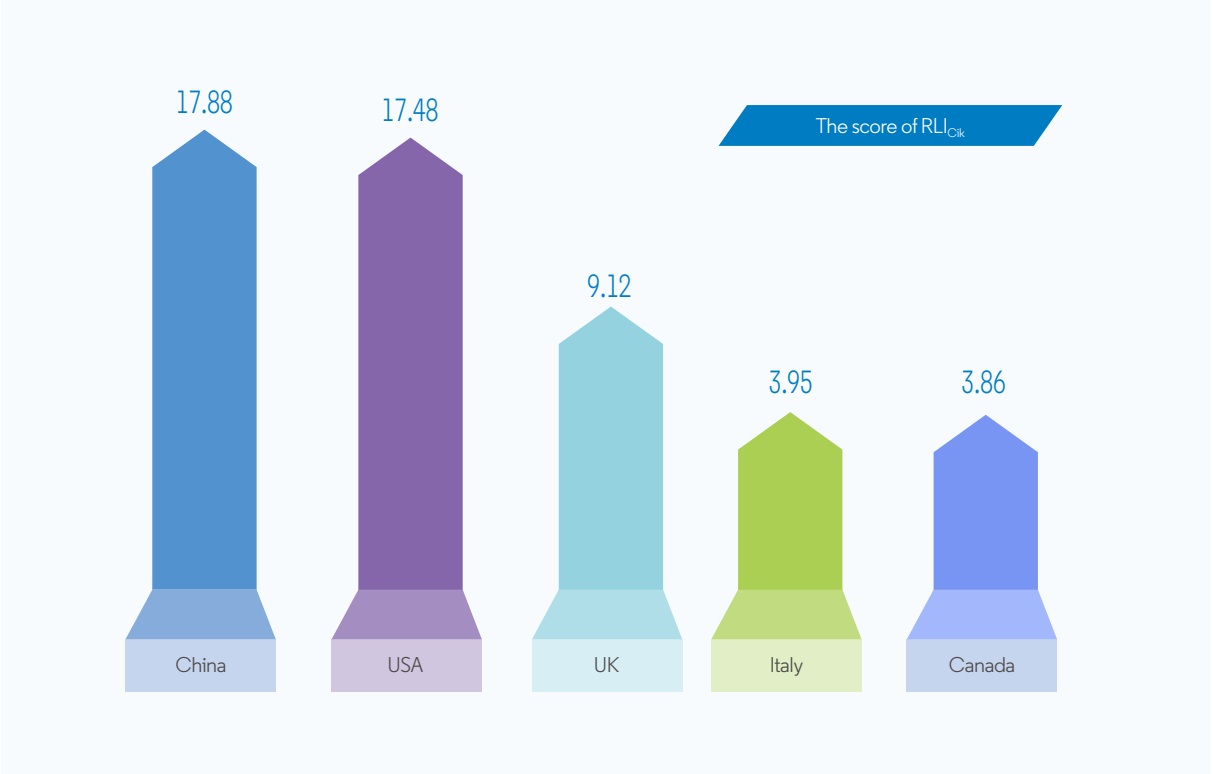
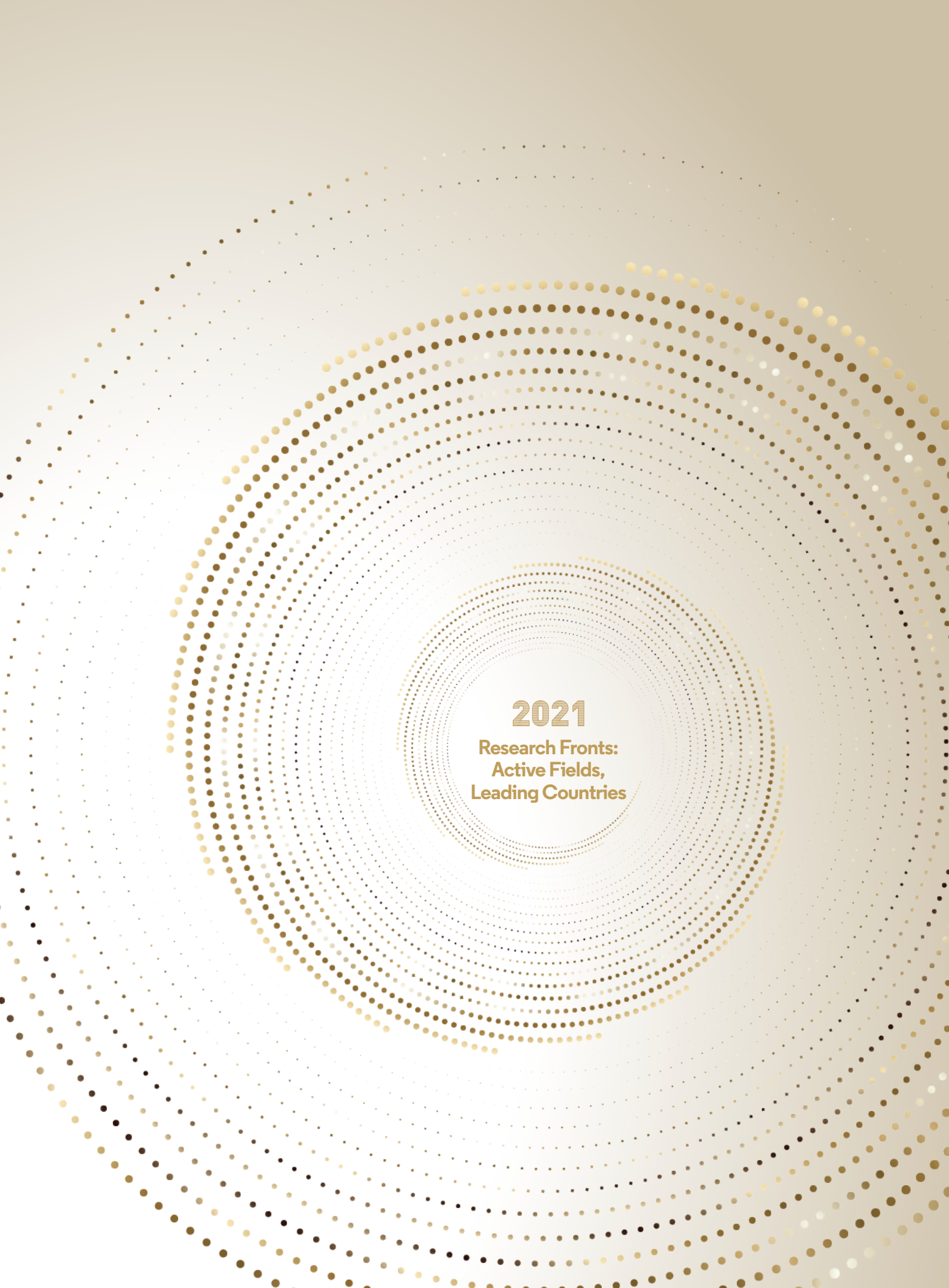


Table 16. The score and rank of Top 5 countries based on RLI_{Cik}, $RFOI_{Cik}$ and $RFII_{Cik}$ in the area of "Economics, psychology and other social sciences"

Indicators	Score					Rank				
	China	USA	UK	Italy	Canada	China	USA	UK	Italy	Canada
RLI_{Cik}	17.88	17.48	9.12	3.95	3.86	1	2	3	4	5
$RFOI_{Cik}$	9.79	9.22	4.31	2.16	2.20	1	2	3	5	4
$RFII_{Cik}$	8.09	8.26	4.81	1.79	1.66	2	1	3	4	5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