Infectious epidemics and the research output of nations: a data-driven analysis

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Abstract: During the last years, several infectious diseases have caused widespread nationwide epidemics that affected information seeking behaviours, people mobility, economics and research trends. Examples of these epidemics are 2003 SARS epidemic in mainland China and Hong Kong, 2014-2016 Ebola epidemic in Guinea and Sierra Leone, 2015-2016 Zika epidemic in Brazil, Colombia and Puerto Rico and the recent COVID-19 epidemic in China and other countries. In this research paper, we investigate the effect of large-scale outbreaks of infectious diseases on the research productivity and landscape of nations through the analysis of the research outputs of main countries affected by SARS, Zika and Ebola epidemics as returned by Web of Science Core Collection. Despite the mobility restrictions and the limitations of work conditions due to the epidemics, we surprisingly found that the research characteristics and productivity of the countries that have excellent or moderate research traditions and communities are not affected by infectious epidemics due to their robust long-term research structures and policy. Similarly, large-scale infectious outbreaks can even boost the research productivity of countries with limited research traditions thanks to international capacity building collaborations provided by organizations and associations from leading research countries.

Keywords: Epidemic, Research productivity, Disease outbreak, Scientometrics

Introduction

By the information age, many high-scale outbreaks of infectious diseases have occurred. Between November 2002 and July 2003, an epidemic of severe acute respiratory syndrome caused by SARS Coronavirus has emerged in Southern China and Hong Kong affecting 17 countries with a mortality rate of 9.6% [1]. From December 2013 to June 2016, a widespread outbreak of Ebola virus-induced severe haemorrhagic fever has occurred in Western Africa mainly Guinea, Liberia and Sierra Leone [2, 3]. From March 2015 to November 2016, a large epidemic of fever, neurological disorders and foetal pathologies caused by Zika virus has been introduced in Brazil and then spread all over the Americas [4]. Since December 2019, an epidemic of a human respiratory disease associated with a new coronavirus of a probable bat origin (so-called 2019-nCoV or COVID-19) has begun in China. The emerging disease is characterized by a sharp appearance of fever, dry cough, headache, shortness of breath and pneumonia. It has disseminated in China and several other countries in a couple of months before becoming a widespread pandemic in March 2020 [5, 6].

The outbreaks of such diseases causes a significant deficiency of supply chain in industry and agriculture, a limitation of provided services particularly healthcare and education, a difficulty of the organization of important expert events, an alteration of global workforce

productivity and mindset, and consequently a loss of the gross national income and trade competitiveness for affected countries [6-8].

From the perspective of Library and Information Science, these infectious epidemics also affected human behaviour of producing, seeking and disseminating information, particularly Internet data and scholarly publications. In fact, the important outbreak of an infectious disease usually causes a severe increase in the publication of scholarly works about the infection [9, 10]. Furthermore, infectious epidemics influence behavior of Internet users probably due to an epidemic of fear induced by mass media [11, 12]. For instance, Ebola epidemic of 2014-2016 has caused a peak of Internet search queries on Ebola virus using Google and Bing in affected countries particularly Liberia, Sierra Leone and Guinea [13, 14]. This epidemic was also coupled with a peak of online news items as well as of satiric and reliable posts about the infection on social media [14-16]. Similar Internet user behaviours were reported as results of other epidemics like Zika epidemic [17, 18] and COVID-19 epidemic in China [19]. In other context, like influenza epidemics, it has been proved that infectious outbreaks are coupled with a rise of pageviews related to concerned diseases in online resources such as Wikipedia [20]. Changes in the tendencies of usage of Internet search engines [21], of social networks [22] and of online resources [20] have been proved to have the power to predict the timely and geographical evolution of studied outbreaks and can consequently be efficient tools alongside other types of data like CO_2 levels' satellite images [23] for the identification, surveillance and control of infectious epidemics all over the world.

In this research paper, we investigate the impact of infectious epidemics on information-related behaviours by assessing the effect of the large-scale outbreaks of infectious diseases on the global research productivity of affected nations through the study of 2003 SARS epidemic, 2014-2016 Ebola epidemic and 2015-2016 Zika epidemic.

Literature review

In his book, Snowden (2019) shows that diseases have not only influence medical science and public health but also transformed the arts, religion, intellectual history and warfare. An issue of more recent interest and less literature coverage is the effects of epidemics on publications [24]. Recently, Bell et al (2020) argue that the virus is not just an impediment but an opportunity as well. They suggest that "Inboxes are daily flooded with requests to contribute to special issues or blogs on the coronavirus, and research funders have been fast to develop funding calls for research on the pandemic". Hence, among the many uncertainties of the COVID-19 pandemic, one clear outcome has been an incitement to publish [25].

The speed and volume of research into the novel coronavirus is unprecedented [26]. A search on WoS identified 14 051 items in the subject Covid during 2020 (up to July 12). During 2019 there were only two articles. The difference of Covid time and previous epidemics becomes apparent when the coronavirus pandemic is compared with the 2003 SARS epidemic. According to Xing et al. (2010), only 7% of studies of the outbreak were

published during the crisis itself [27]. The current investigation is among the few ones aiming to identify the impact of epidemics and pandemics on scientific publishing.

Scientific small countries present particular interest on issues of priorities and reaction to environment. The limited size of their scientific community means that authorities have difficult choices to make. Pouris *et al* (2014) identified that foreign researchers appear to influence priorities and research solution in the African Continent, mainly because of the availability of research resources [28]. Similarly, an EC report [29] identified that the framework programs had a substantial impact in the African continent. Researchers in the continent collaborated with the European partners and continued publishing in the common topics after the end of collaboration. It will be interesting to identify the performance of scientific small countries in the threat of epidemics and pandemics.

Methods

Using Web of Science web interface [30], we extracted detailed statistics of research productivity for the countries where the outbreaks of SARS, Ebola and Zika is widespread as shown in Table 1. Availability of data was the main reason for the choice of the WoS.

Table 1: Assessed epidemics and countries

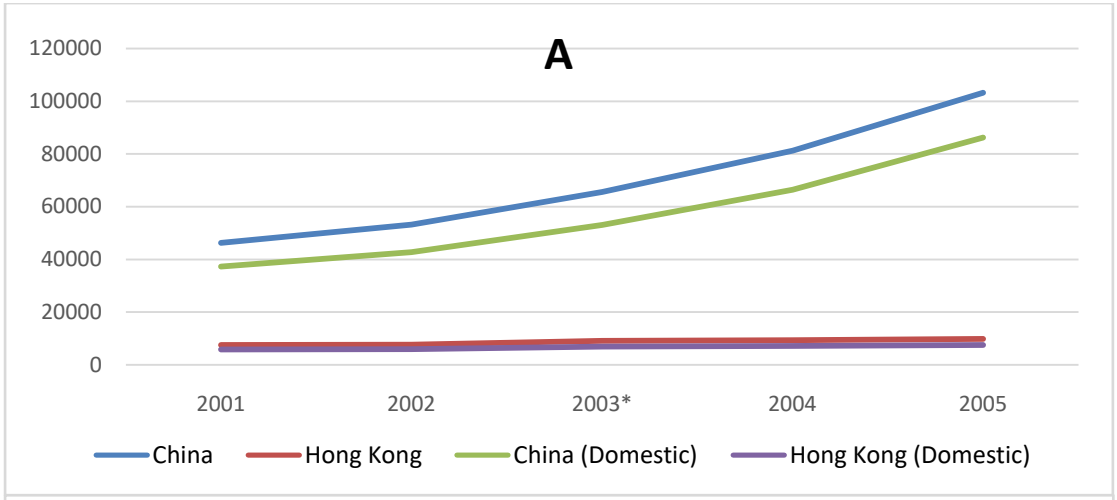
Epidemic	Outbreak years	Countries
SARS	2003	China
		Hong Kong
Ebola	2014-2016	Guinea
		Sierra Leone
Zika	2015-2016	Brazil
		Colombia
		Puerto Rico

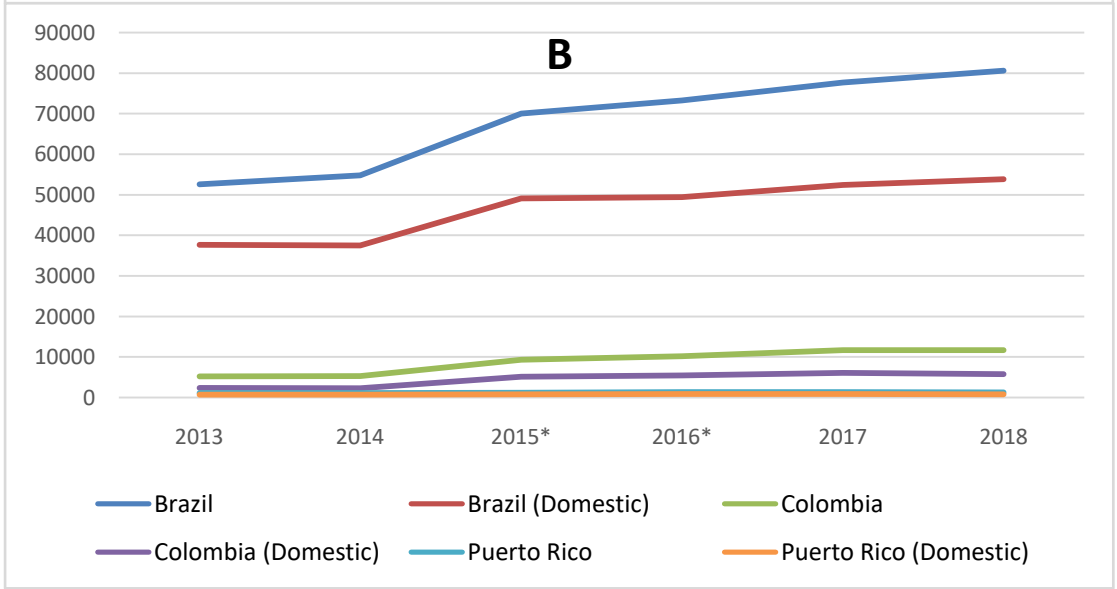
For each country, we extract the quantity of domestic and international research output for the years of the infectious outbreak and for two years before and after the epidemic. A research output is considered as domestic when it was not issued from an international scholarly collaboration. We also extract the source scholarly journals, the languages, the research areas and the types of the publications of each country as well as the co-authoring countries and institutions for the publications of each country during the outbreak and one year before and after the epidemic. We restricted our query to the publications indexed by Web of Science Core Collection (SCI-E, SSCI, A&HCI, CPCI and ESCI) and we retrieved obtained data on March 2, 2020. We do not take into consideration the research collaborations between Hong Kong and China and the ones between Puerto Rico and United States so that the results would not be biased because of the political situation of Hong Kong and Puerto Rico as a respective special administration region of China and United States [31].

Results

Number of publications, institutions and international collaboration

When assessing the yearly evolution of research productivity of China and Hong Kong between 2001 and 2005, we found that the number of scholarly publications and the quantity of domestic research outputs of these two countries steadily increased during the 2001-2005 and did not seem to be influenced by 2003 SARS Coronavirus as shown in Fig. 1A. When reproducing the same measure to Brazil, Colombia and Puerto Rico between 2013 and 2018, we found that the domestic research productivity and global research productivity of these countries regularly evolved and was not altered by 2015-2016 Zika epidemic as shown in Fig. 1B. Surprisingly, this is not the situation when we assessed the effect of 2014-2016 Ebola epidemic on the research productivity of Guinea and Sierra Leone. As shown in Fig. 1C, the research productivity of Guinea and Sierra Leone has largely increased during the epidemic before beginning to slightly decrease in 2017 and 2018. However, the epidemic did not seem to significantly influence domestic research output that remained quite stable between 2012 and 2018.





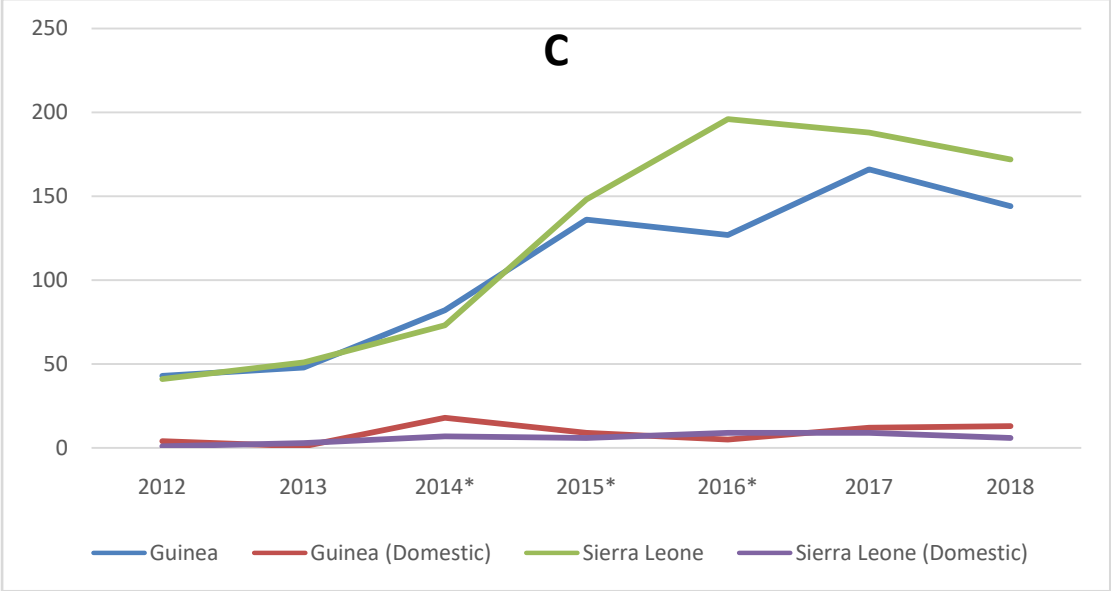


Figure 1: Overall and domestic research productivity of nations during epidemics (*): A) China and Hong Kong between 2001 and 2005, B) Brazil, Colombia and Puerto Rico between 2013 and 2018, C) Guinea and Sierra Leone between 2012 and 2018

When investigating the evolution of international research collaboration of China and Hong Kong between 2001 and 2005, we found that the international collaboration rate of Hong Kong remained stable around 23% during the 2001-2005 as mentioned in Fig. 2A. However, the one of China was steady near 19% until 2003 before slightly decreasing in 2004 (18.14%) and 2005 (16.40%) due to the epidemic. This stability of international collaboration rates is also revealed for Brazil when affected by 2015-2016 Zika epidemic. However, this is not the situation for Colombia where the international collaboration rate declined from 56.68% in 2014 to 45.05% in 2015 before becoming slightly increasing since 2016 and for Puerto Rico where the international collaboration has regularly increased since 2015 as shown in Fig. 2B. When examining the international collaboration rates for the countries majorly affected by 2014-2016, we found that this rate in more than 90% before and after the epidemic. However, this rate significantly decreased to 78.05% for Guinea and to 90.41% for Sierra Leone in 2014, the first year of the outbreak of Ebola virus, as shown in Fig. 2C.

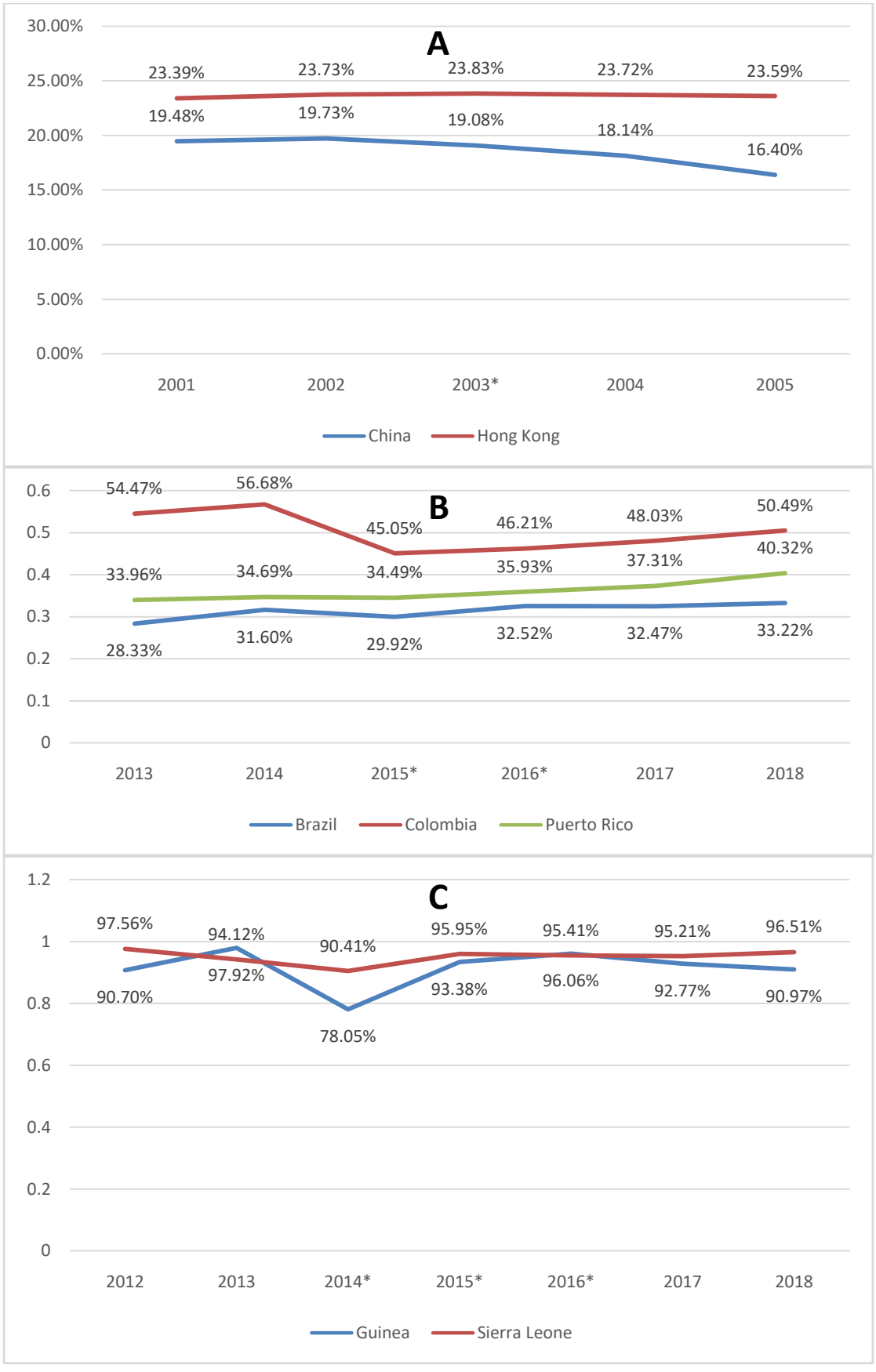


Figure 2: International Collaboration rates of nations during epidemics (*): A) China and Hong Kong between 2001 and 2005, B) Brazil, Colombia and Puerto Rico between 2013 and 2018, C) Guinea and Sierra Leone between 2012 and 2018

When trying to understand the stability of research productivity of China and Hong Kong in spite of SARS epidemic, we stated that the most productive research institutions of the two affected countries during the epidemic are the same ones that mostly produced the global research outputs of the two nations before and after the outbreak as shown in Fig. 3.

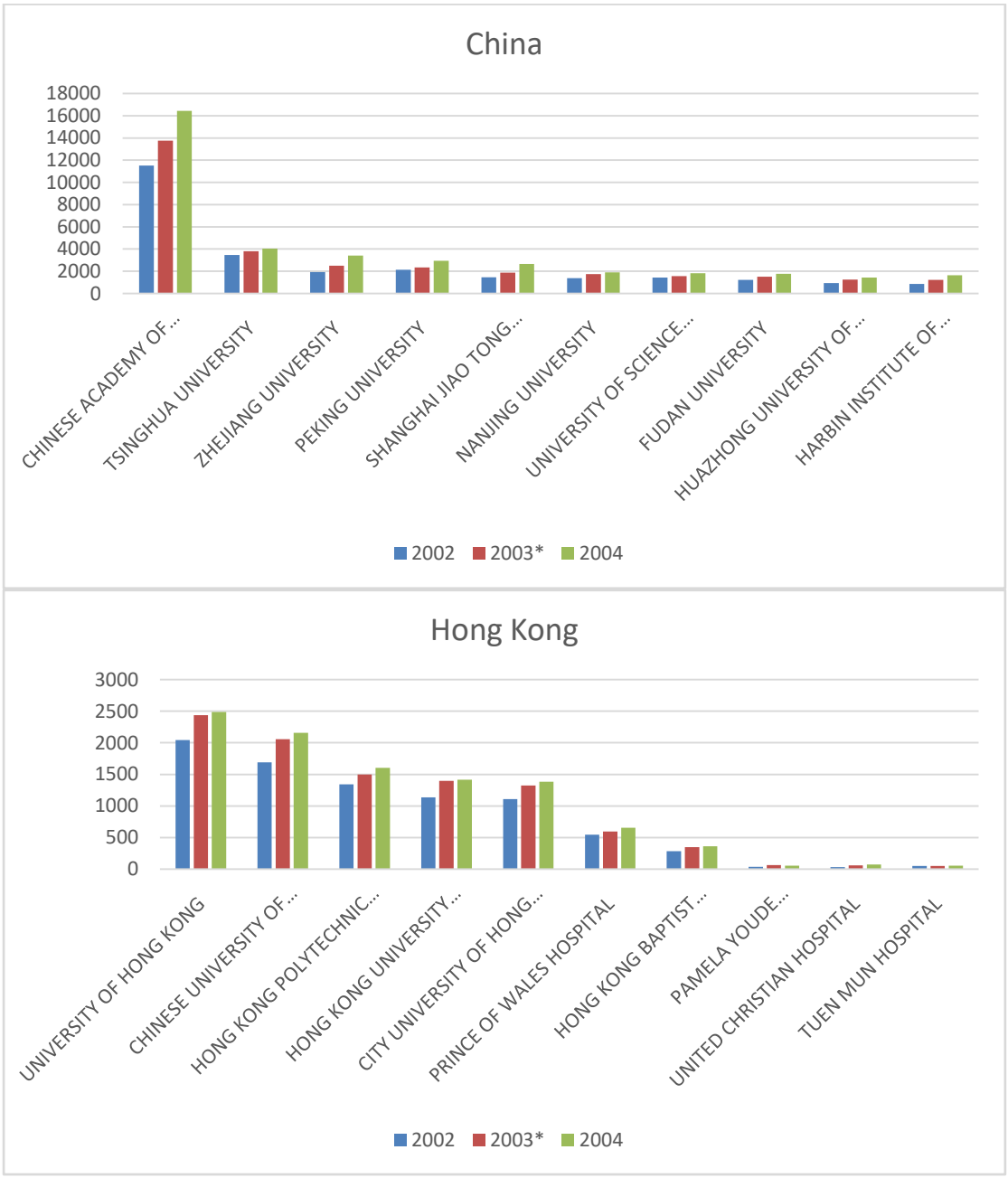


Figure 3: Evolution of the research productivity of the best productive institutions of China and Hong Kong during the 2003 SARS epidemic

This stability of institutional distributions of scholarly publications is also reported for Brazil and Puerto Rico during Zika epidemic as shown in Fig. 4. This also applies to Colombia with the exception that there are two universities that had poor research productivity before the epidemic and that became among the ten most productive research institutions in Colombia since 2015: *Universidad Distrital Francisco José de Caldas* and *Universidad Pedagogica y Tecnologica de Colombia UPTC*.

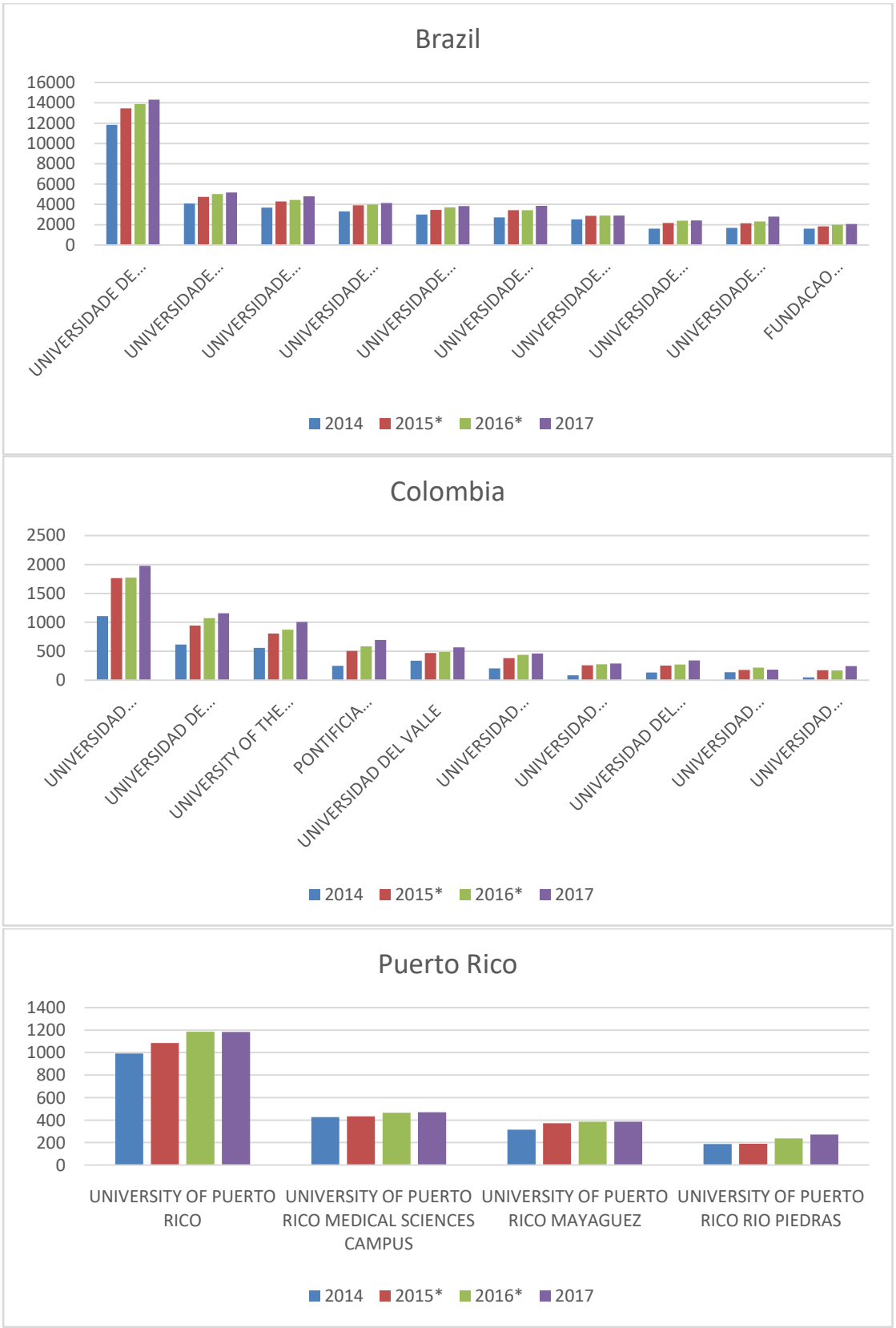


Figure 4: Evolution of the research productivity of the best productive institutions of Brazil, Colombia and Puerto Rico during 2015-2016Zika Epidemic

When seeing the situation of Guinea and Sierra Leone, we remarked that each institution of the two countries issued less than 10 publications in 2013. However, the number of

publications for the most productive institutions of the two countries has largely increased since 2014 to reach more than 20 publications in 2017 for three institutions in Guinea and two institutions in Sierra Leone. There are several institutions that were not productive in 2012 but became among the most published ones in Guinea and Sierra Leone by 2017 like *Centre National de Formation et de Recherche en Santé Rurale* (Guinea) and *Kenema Government Hospital* (Sierra Leone). It is clear as shown in Fig. 5 that this rise of the production of research output did not involve institutions not working on human pathologies such as *Institut Supérieur des Sciences et de Médecine Véterinaire de Dalaba* (Guinea) and has mostly influenced the main health administrations and research institutions in Guinea and Sierra Leone.

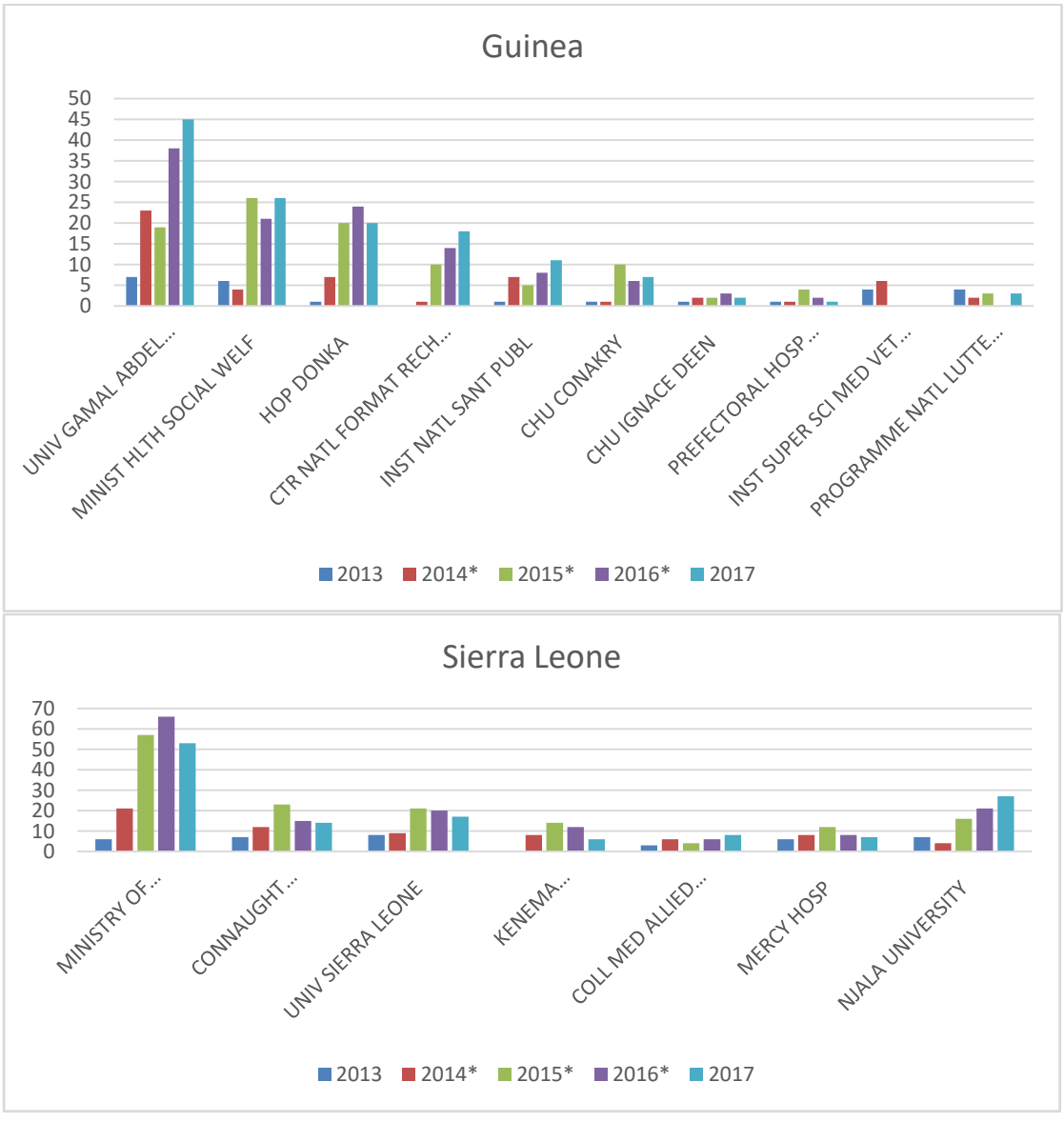


Figure 5: Evolution of the research productivity of the best productive institutions of Guinea and Sierra Leone during the 2014-2016 Ebola epidemic

When seeing the reasons behind the steadiness of international collaboration rates of China and Hong Kong between 2001 and 2005 despite SARS epidemic, we found that the best countries collaborating with China and Hong Kong during the SARS epidemic are the same

countries that mostly collaborate with these two affected nations before and after the outbreak as shown in Fig. 6. The only difference between China and Hong Kong is the evolution of the research collaboration between China and other countries remained stable before and after the epidemic while the evolution of the scholarly collaboration between Hong Kong and other nations has been slightly slowed after the outbreak.

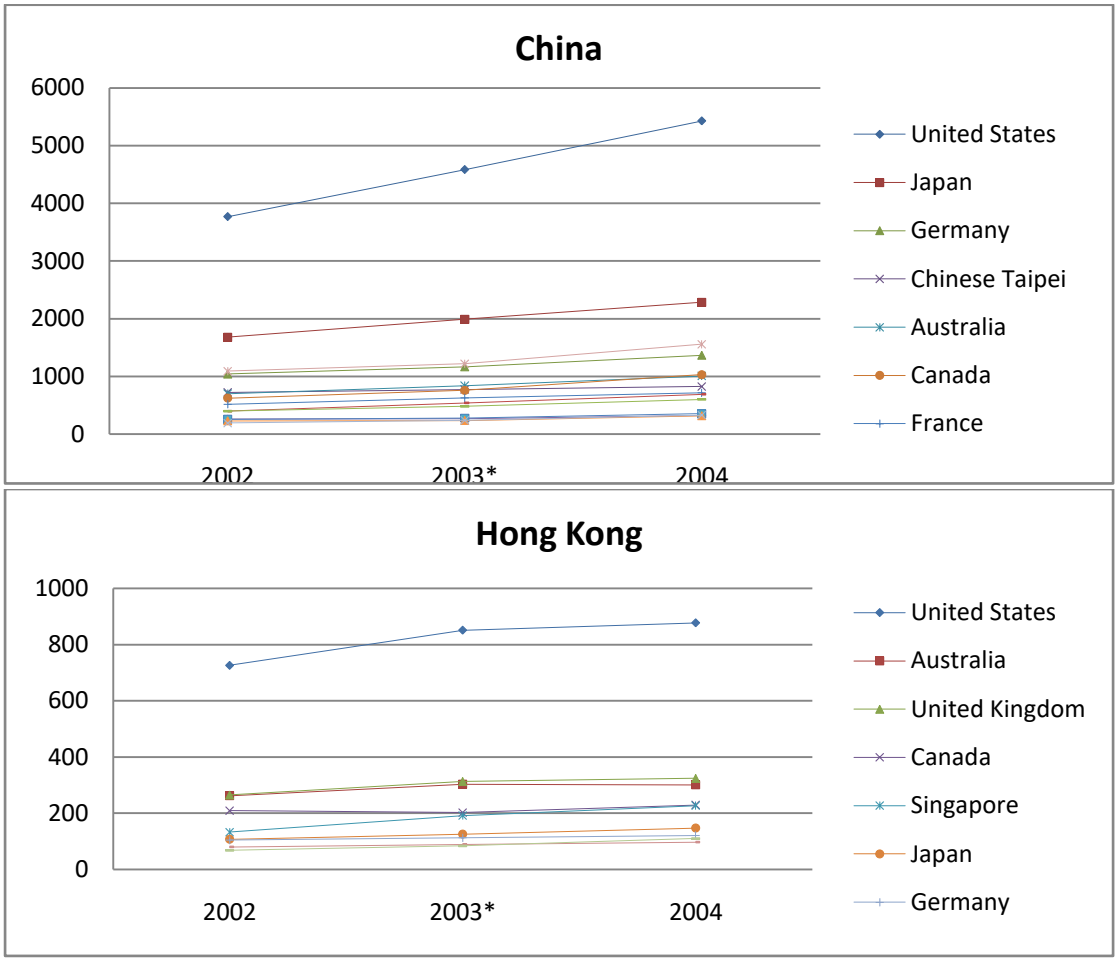
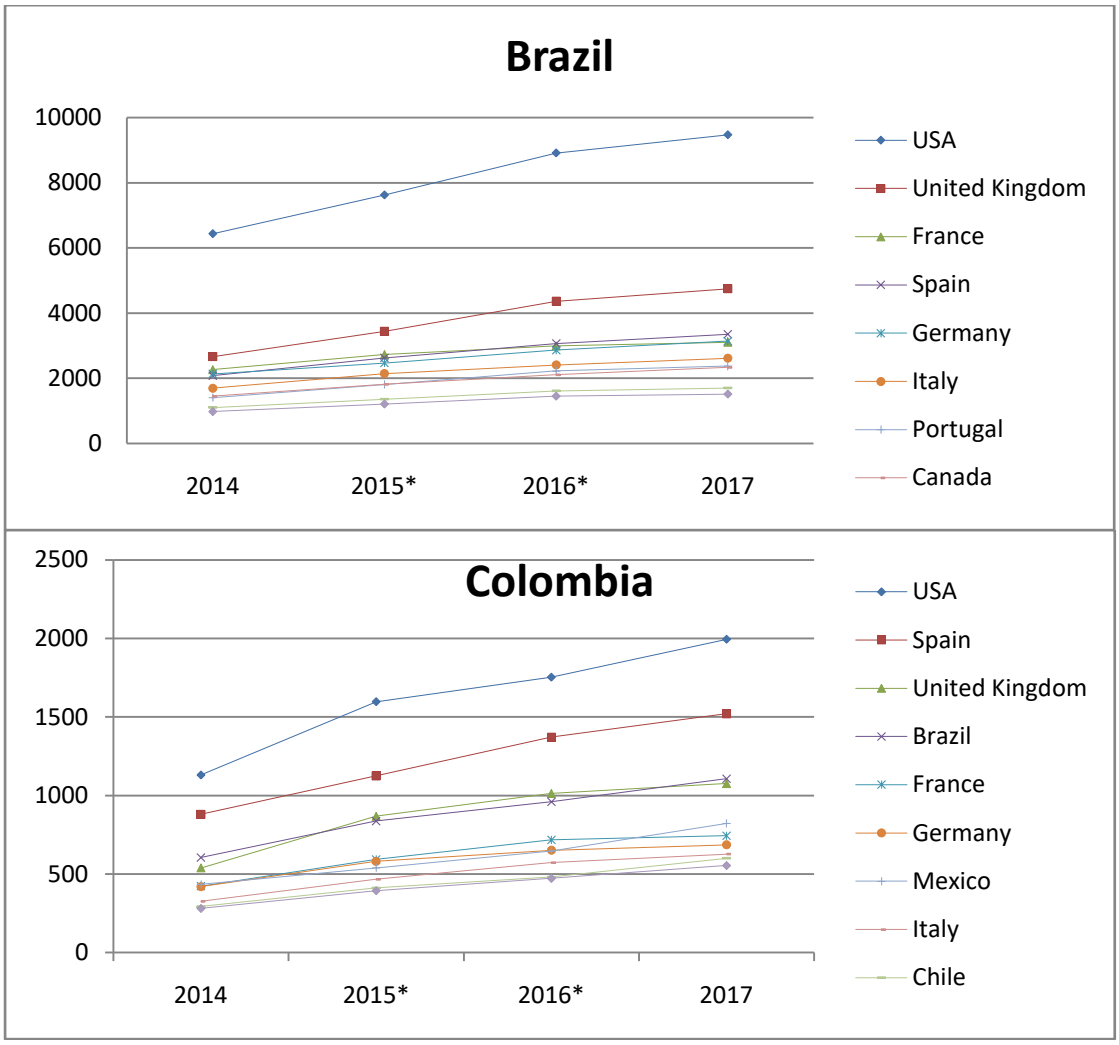


Figure 6: Evolution of the research collaboration output of the best countries collaborating with China (top) and Hong Kong (bottom) during the 2003 SARS epidemic[1]

When verifying the international country-level research collaborations of Brazil, Colombia and Puerto Rico during the 2015-2016 Zika epidemic, we found that the countries mostly collaborating with these three affected nations are the same before, during and after Zika outbreak as shown in Fig. 7. However, it is clear that the evolution of the international collaborations of the three countries have different behaviours. The growth of the research collaboration of Brazil with other countries has been regular from 2014 to 2016 before slightly decreasing in 2017. As for Colombia, the rise of its research collaboration with other countries has slowed down during the outbreak. In 2017, the rise of the research collaboration of Colombia with countries from the Americas has been absolutely refreshed. However, the research collaboration with other countries mainly the European ones

[1] Collaborations between China and Hong Kong are not considered

continued to slow down. The behaviour of Puerto Rico with its research collaborations with other countries is just the reverse as the one of Colombia.



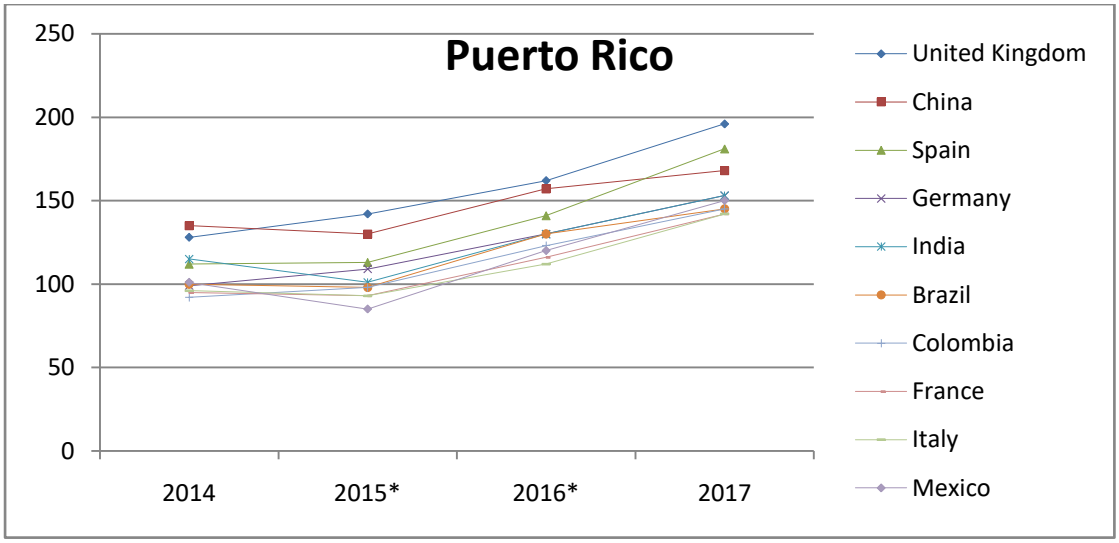


Figure 7 : Evolution of the research collaboration output of the best countries collaborating with Brazil, Colombia and Puerto Rico during the 2015-2016 Zika Epidemic[2]

Concerning Guinea and Sierra Leone during 2014-2016 Ebola outbreak, the situation seems to be more complicated. There are several countries that were not significantly collaborating with these affected nations before the epidemic (Belgium and Ivory Coast for Guinea and Canada, China, Australia and Italy for Sierra Leone) but that became among the ten countries mostly collaborating with these two affected nations during and after the outbreak as shown in Fig. 8. These countries had sped up the quantitative evolution of their scholarly collaboration with Guinea and Sierra Leone during the epidemic before slowing it down shortly after the epidemic. There are countries that were among the mostly collaborating ones with Guinea or Sierra Leone before the epidemic but that gradually left their place as a prestigious research partner for these affected nations during the epidemic. The examples that are shown in Fig. 8 are China for Guinea and Netherlands for Sierra Leone. Other examples are Benin (4 publications, 8.3% of Guinea publications), South Africa (4 publications, 8.3% of Guinea publications) and Uganda (3 publications in 2013, 6.3% of Guinea publications) for Guinea and France (4 publications in 2013, 7.8% of Sierra Leone publications), Ghana (4 publications in 2013, 7.8% of Sierra Leone publications) and Spain (3 publications in 2013, 5.9% of Sierra Leone publications) for Sierra Leone. These countries returned to have a major role in scholarly research in Guinea and Sierra Leone after the outbreak. For example, Ghana collaborated with Sierra Leone in a record of 19 scholarly publications in 2017.

[2] Collaborations between United States of America and Puerto Rico are not considered.

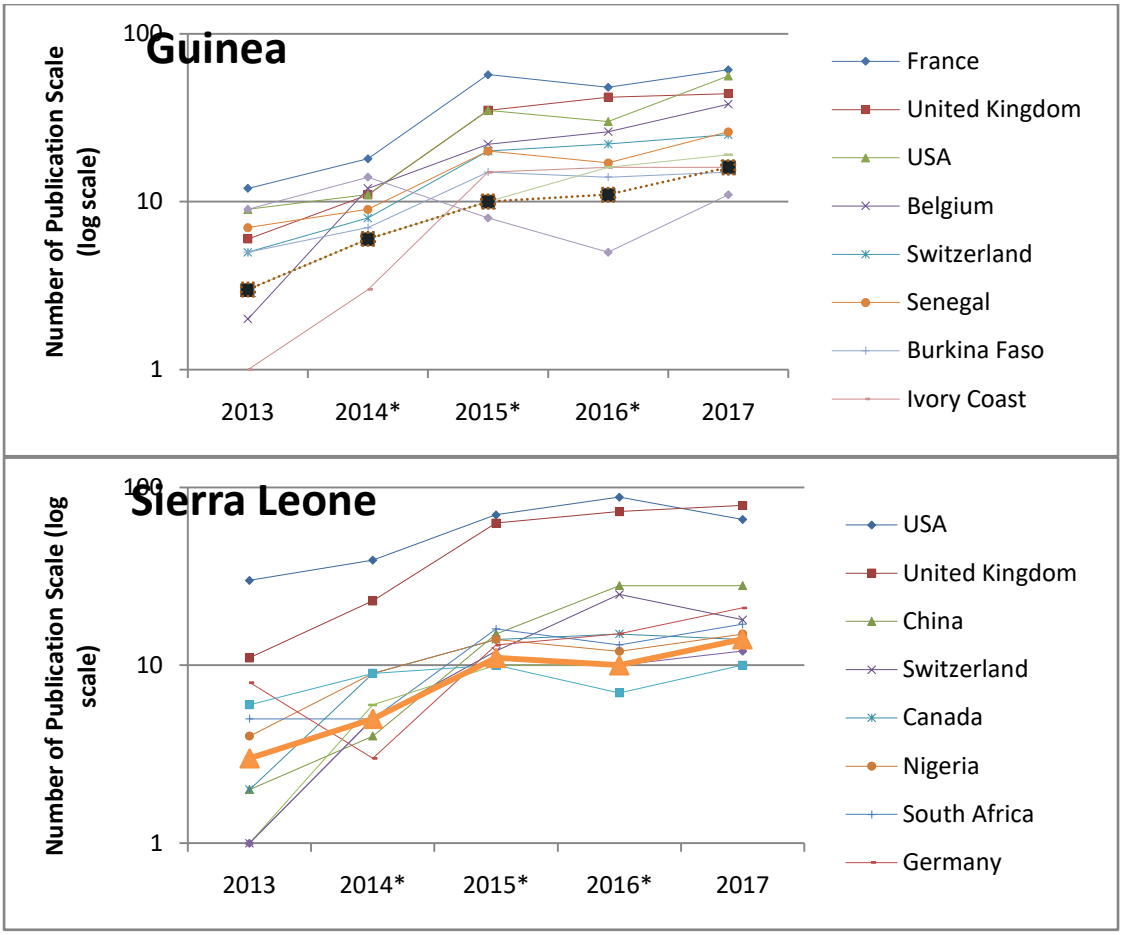


Figure 8: Evolution of the research collaboration output of the best countries collaborating with Guinea and Sierra Leone during 2014-2016 Ebola epidemic

At an institutional level, it is clear when dealing with SARS epidemic that the foreign institutions mostly collaborating with China during the outbreak had stable research collaborations with Chinese institutions before and after the epidemic as shown in Table 2 and this explains the steadiness of country-level research collaborations of China.

Table 2: Research collaboration output of the ten foreign institutions mostly collaborating with China during SARS Epidemic[3,4]

Institution	Country	2002	2003*	2004
UNIVERSITY OF CALIFORNIA	United States	428	511	585
CHINA MEDICAL UNIVERSITY TAIWAN	Chinese Taipei	306	323	322
NATIONAL UNIVERSITY OF SINGAPORE	Singapore	212	292	364
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	France	228	291	283
UNITED STATES	United	207	246	307

[3] (*) The year of SARS epidemic
[4] Collaborations between China and Hong Kong are not considered.

DEPARTMENT OF ENERGY DOE	States			
MAX PLANCK SOCIETY	Germany	175	216	221
UNIVERSITY OF TOKYO	Japan	166	209	190
UNIVERSITY OF TEXAS	United States	157	186	272
UNIVERSITY OF LONDON	United Kingdom	160	178	293
NANYANG TECHNOLOGICAL UNIVERSITY	Singapore	140	178	228
NATIONAL TAIWAN UNIVERSITY	Chinese Taipei	160	160	180

This important remark also applies to Hong Kong as shown in Table 3 where the foreign institutions working with Hong Kong on scholarly research efforts during the epidemic collaborated with Hong Kong before the outbreak and continued to have research ties with this nation after the outbreak. The only difference between the international institutional collaborations of China (Table 2) and the ones of Hong Kong (Table 3) is that mainland China establish long-term research collaborations with the central research services of the countries they collaborate with such as CNRS (France) and DOE (United States) or with international prestigious science societies like Max Planck Society by contrast to Hong Kong.

Table 3: Research collaboration output of the ten foreign institutions mostly collaborating with Hong Kong during SARS Epidemic[5,6]

Institution	Country	2002	2003*	2004
UNIVERSITY OF CALIFORNIA	United States	74	104	87
QUEEN ELIZABETH HOSP	Australia	71	64	72
NATIONAL UNIVERSITY OF SINGAPORE	Singapore	63	80	103
UNIVERSITY OF LONDON	United Kingdom	59	56	57
UNIVERSITY OF SYDNEY	Australia	59	70	56
NANYANG TECHNOLOGICAL UNIVERSITY	Singapore	43	73	72
UNIVERSITY OF GEORGIA	United States	39	57	33
PRINCESS MARGARET HOSP	Canada	37	62	68
UNIVERSITY OF TORONTO	Canada	36	35	36
AUGUSTA UNIVERSITY	United States	24	39	20

When seeing the foreign institutions mostly collaborating with Brazil (Table 4), Colombia (Table 5) and Puerto Rico (Table 6), we found that the institutions that mostly collaborate with these countries during Zika epidemic are quite the same ones that collaborate with

[5] Collaborations between China and Hong Kong are not considered.
[6] (*) The year of SARS epidemic.

these nations before and after the epidemic. By contrast to Hong Kong and similarly to China, research collaborations of the countries affected by the Zika outbreak are dominated by nationwide research structures such as CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS (France), CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS CSIC (Spain), UNITED STATES DEPARTMENT OF ENERGY DOE (United States), CHINESE ACADEMY OF SCIENCES (China) and RUSSIAN ACADEMY OF SCIENCES (Russian Federation) and by worldwide scholarly societies such as HELMHOLTZ ASSOCIATION.

Table 4: Research collaboration output of the ten foreign institutions mostly collaborating with Brazil during Zika Epidemic[7]

Organizations-Enhanced	Country	2014	2015*	2016*	2017
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	France	1083	1289	1514	1543
UNIVERSITY OF CALIFORNIA SYSTEM	United States	817	1081	1313	1279
HARVARD UNIVERSITY	United States	514	714	824	892
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS CSIC	Spain	562	701	792	821
UNIVERSITY OF TEXAS SYSTEM	United States	483	687	780	725
UNIVERSITY OF LONDON	United Kingdom	506	649	799	909
UNIVERSITE PARIS SACLAY	France	520	583	657	636
SORBONNE UNIVERSITE	France	456	561	677	657
UNITED STATES DEPARTMENT OF ENERGY DOE	United States	382	483	670	612
UNIVERSIDADE DE LISBOA	Portugal	364	492	658	693
Top 10 Threshold		407	492	657	636

Table 5: Research collaboration output of the ten foreign institutions mostly collaborating with Colombia during Zika Epidemic[8]

Organizations-Enhanced	Country	2014	2015*	2016*	2017
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS CSIC	Spain	262	379	414	410
UNIVERSITY OF CALIFORNIA SYSTEM	United States	295	367	410	404
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	France	270	363	412	444
UNIVERSITE PARIS SACLAY	France	200	304	331	332
SAPIENZA UNIVERSITY ROME	Italy	173	269	301	316
RUSSIAN ACADEMY OF SCIENCES	Russian Federation	172	266	304	320
CNRS NATIONAL INSTITUTE OF NUCLEAR AND PARTICLE PHYSICS IN2P3	France	185	265	296	293
UNIVERSIDADE DE SAO PAULO	Brazil	176	245	315	299
ISTITUTO NAZIONALE DI FISICA NUCLEARE	Italy	172	263	292	299

[7] (*) The years of Zika epidemic
[8] (*) The years of Zika epidemic

UNIVERSITY OF BOLOGNA	Italy	173	265	289	318
Top 10 Threshold		194	263	292	299

Table 6: Research collaboration output of the ten foreign institutions mostly collaborating with Puerto Rico during Zika Epidemic[9,10]

Organizations-Enhanced	Country	2014	2015*	2016*	2017
CHINESE ACADEMY OF SCIENCES	China	88	83	102	128
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	France	84	77	102	130
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS CSIC	Spain	79	77	97	132
IMPERIAL COLLEGE LONDON	United Kingdom	82	72	101	127
HELMHOLTZ ASSOCIATION	Germany	80	73	97	124
UNIVERSITY OF FLORENCE	Italy	77	75	95	119
RUSSIAN ACADEMY OF SCIENCES	Russian Federation	81	72	97	121
UNIVERSITY OF DELHI	India	78	73	96	120
PEKING UNIVERSITY	China	78	70	98	121
UNIVERSITES DE STRASBOURG ETABLISSEMENTS ASSOCIES	France	78	71	96	120
UNIVERSITY OF PISA	Italy	79	70	97	123
UNIVERSITY OF PAVIA	Italy	78	73	94	120
Top 10 Threshold		79	72	96	121

However, this does not seem to be the situation when seeing the foreign institutions mostly collaborating with Guinea (Table 7) and Sierra Leone (Table 8) during the Ebola outbreak of 2014-2016. Effectively, as shown in Tables 7, 3 of the 10 foreign institutions mostly collaborating with Guinea were not among the top 10 foreign organizations jointly working with Guinea before and after the outbreak. Similarly, 7 of the 10 foreign institutions mostly collaborating with Sierra Leone were not among the top 10 foreign institutions working with this country before the epidemic and 3 institutions were the among the top 10 foreign institutions mostly working with Sierra Leone after the outbreak.

This change in the landscape of collaborating institutions with Guinea and Sierra Leone during Ebola outbreak confirms the changing patterns of the country-level collaborations of Guinea and Sierra Leone during the Ebola epidemic shown in Fig. 8. This change is associated by the installation of high-scale biomedical research collaborations with Guinea and Sierra Leone driven by World Health Organization during the Ebola outbreak as shown in Tables 7 and 8. These biomedical research collaborations did not alter already existing research collaborations between these two affected countries and charity associations like *Doctors Without Borders* (Switzerland) and development research institutions like *Institut de Recherche pour le Développement* (France).

[9] Research collaborations between Puerto Rico and United States are not taken into consideration

[10] (*) The years of Zika epidemic

Table 7: Research collaboration output of the ten foreign institutions mostly collaborating with Guinea during Ebola outbreak[11]

Organizations-Enhanced	Country	2013	2014*	2015*	2016*	2017
WORLD HEALTH ORGANIZATION	Switzerland	3	7	18	21	21
INSTITUT DE RECHERCHE POUR LE DEVELOPPEMENT IRD	France	7	9	19	13	23
INSTITUTE OF TROPICAL MEDICINE ITM	Belgium	0	6	16	17	20
DOCTORS WITHOUT BORDERS	Switzerland	7	5	16	18	19
UNIVERSITY OF LONDON	United Kingdom	4	9	15	10	13
LONDON SCHOOL OF HYGIENE TROPICAL MEDICINE	United Kingdom	4	9	13	8	11
INSTITUT NATIONAL DE LA SANTE ET DE LA RECHERCHE MEDICALE INSERM	France	2	3	14	10	24
LE RESEAU INTERNATIONAL DES INSTITUTS PASTEUR RIIP	France	4	6	7	10	14
CIRAD	France	3	6	11	5	6
BERNHARD NOCHT INSTITUT FUR TROPENMEDIZIN	Germany	1	4	5	10	9
Top 10 Threshold		3	4	7	8	13

Table 8: Research collaboration output of the ten foreign institutions mostly collaborating with Sierra Leone during Ebola outbreak[12]

Organizations-Enhanced	Country	2013	2014*	2015*	2016*	2017
UNIVERSITY OF LONDON	United Kingdom	2	6	26	23	24
WORLD HEALTH ORGANIZATION	Switerland	1	5	13	20	18
CENTERS FOR DISEASE CONTROL PREVENTION USA	United States	0	5	11	18	25
HARVARD UNIVERSITY	United States	1	6	12	14	12
JOHNS HOPKINS UNIVERSITY	United States	7	13	9	10	5
LONDON SCHOOL OF HYGIENE TROPICAL MEDICINE	United Kingdom	0	1	15	14	12
TULANE UNIVERSITY	United States	1	6	10	12	9
COLUMBIA UNIVERSITY	United States	6	9	12	6	2
UNIVERSITY OF CALIFORNIA SYSTEM	United States	2	2	12	11	10
JOHNS HOPKINS BLOOMBERG SCHOOL OF PUBLIC HEALTH	United States	6	11	6	8	2
Top 10 Threshold		3	5	10	10	10

[11] (*) The years of Ebola outbreak
[12] (*) The years of Ebola outbreak

Publication types, languages, research areas, and journals

When seeing the publication types for China and Hong Kong between 2002 and 2004, we remarked that the distribution of the research publications of these countries has not changed during 2003 SARS outbreak. The research output of these two countries remained mostly represented in the form of articles and of proceedings papers as shown in Fig. 9.

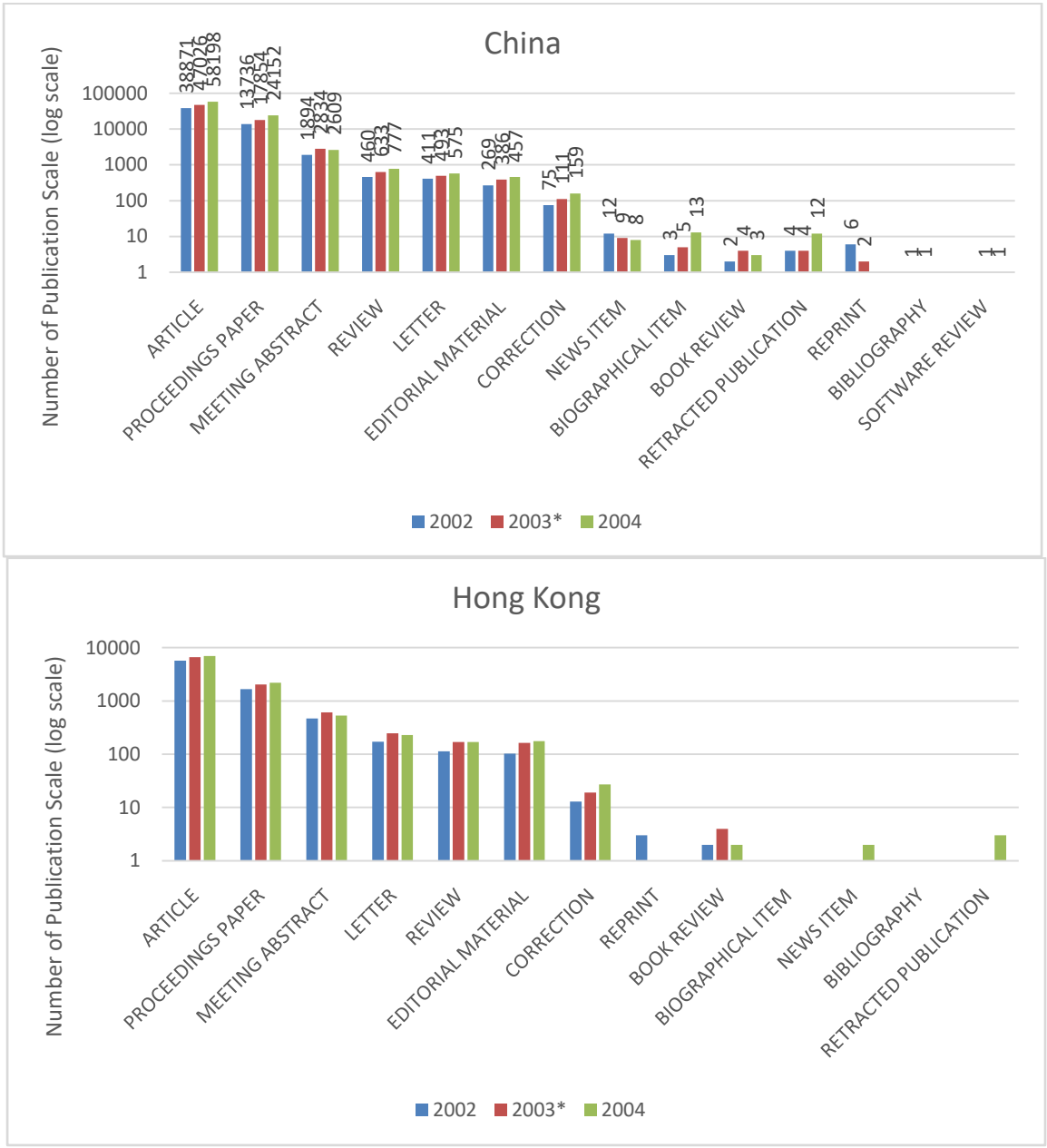
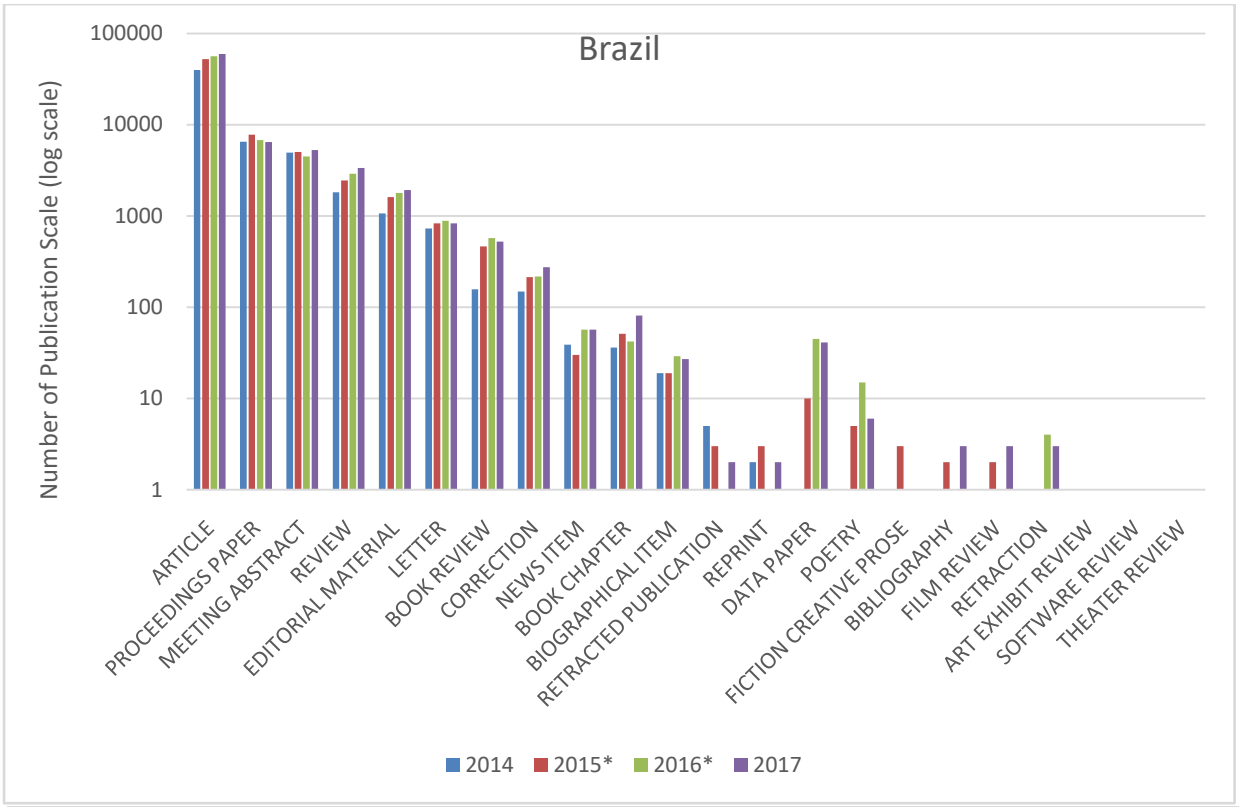


Figure 9: Types of the scholarly publications of China and Hong Kong between 2002 and 2004[13]

The same observation is identified for Brazil, Colombia and Puerto Rico during Zika epidemic as shown in Fig. 10 with the unique exception that there has been a significant increase of the production of a new type of scholarly publications (so-called Data paper) since 2015.

[13] (*) Year of SARS epidemic


Brazil
Number of Publication Scale (log scale)
100000
10000
1000
100
10
1
ARTICLE
PROCEEDINGS PAPER
MEETING ABSTRACT
REVIEW
EDITORIAL MATERIAL
LETTER
BOOK REVIEW
CORRECTION
NEWS ITEM
BOOK CHAPTER
BIOGRAPHICAL ITEM
RETRACTED PUBLICATION
REPRINT
DATA PAPER
POETRY
FICTION CREATIVE PROSE
BIBLIOGRAPHY
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RETRACTION
ART EXHIBIT REVIEW
SOFTWARE REVIEW
THEATER REVIEW
2014
2015*
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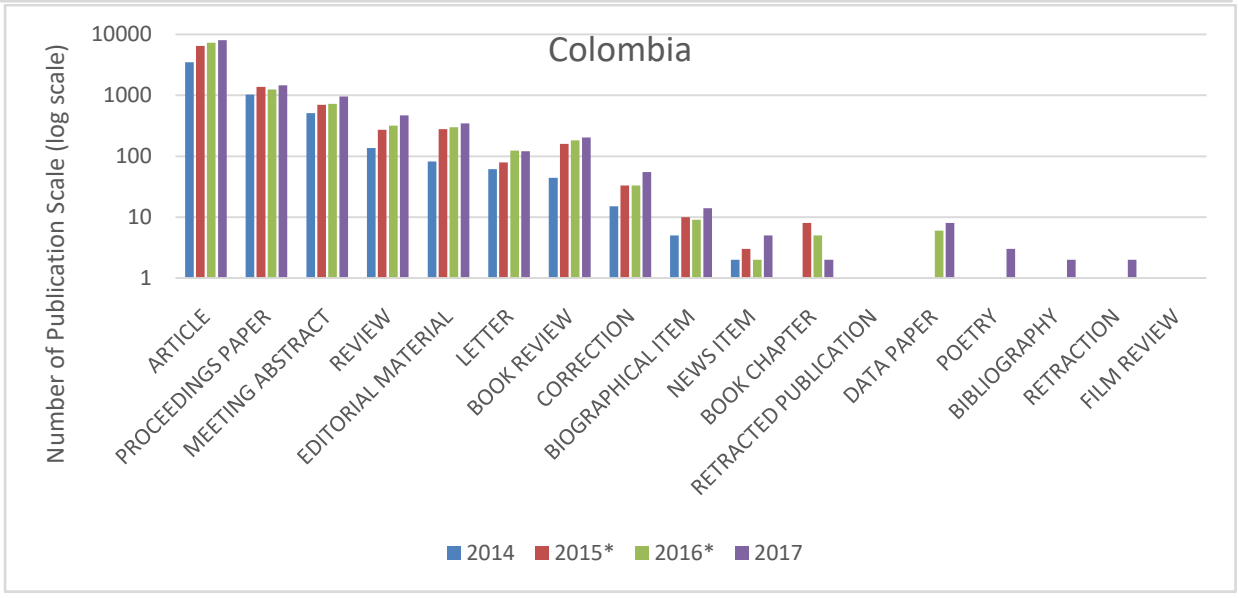
Colombia
Number of Publication Scale (log scale)
10000
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100
10
1
ARTICLE
PROCEEDINGS PAPER
MEETING ABSTRACT
REVIEW
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LETTER
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CORRECTION
BIOGRAPHICAL ITEM
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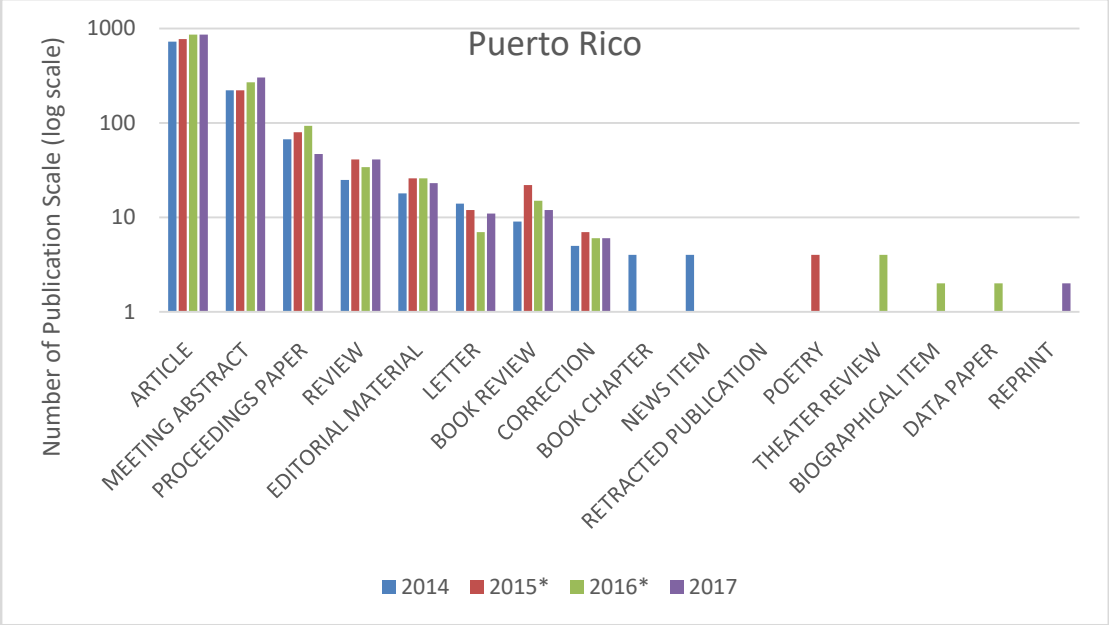
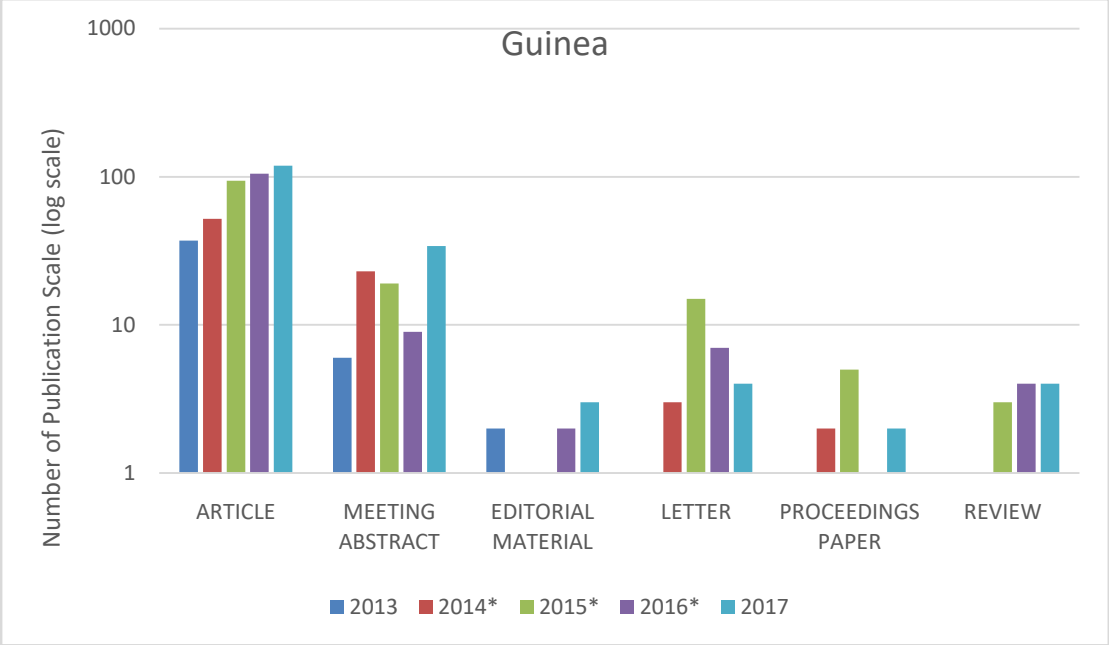


Figure 10: Types of the scholarly publications of Brazil, Colombia and Puerto Rico between 2014 and 2017[14]

Although many patterns of the research outputs of Guinea and Sierra Leone have changed during Ebola epidemic, we found that the distribution of the scholarly output of these two countries by publication types has practically not changed just similarly as China and Hong Kong during 2003 SARS outbreak as shown in Fig. 11.



[14] (*) Years of Zika epidemic

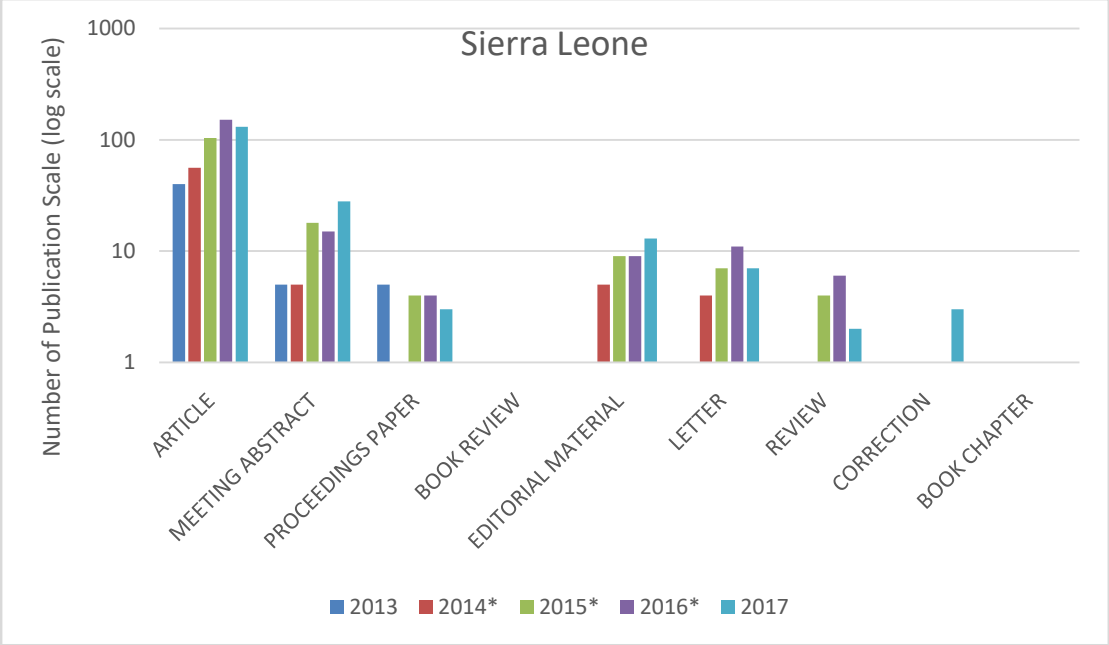
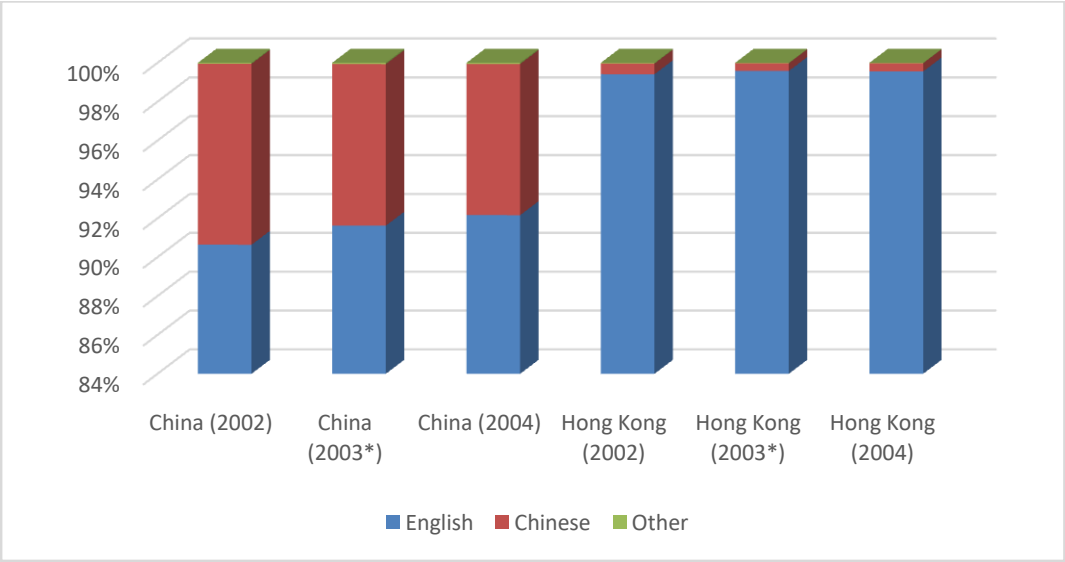


Figure 11: Types of the scholarly publications of Guinea and Sierra Leone between 2013 and 2017[15]

When investigating the evolution of the language distribution of the scholarly publications of the assessed nations during the studied epidemics, we found that the rates of representation of languages in the scientific outputs of affected languages do not seem to vary during infectious outbreaks. As shown in Fig. 12, the research production is always dominated by English followed by the first language of each country. The unique exception to the stability of the language distribution of scholarly outputs is the sharp increase of the rate of publications in mother tongues between 2014 and 2015.



[15] (*) Years of Ebola outbreak

Figure 12: Language rates of the scholarly publications of the studied countries during the analysed epidemics[16]

When examining the evolution of the research areas of assessed countries during epidemics, we found that the disciplinary distribution of the scholarly output of China and Hong Kong remained almost constant during the SARS epidemic with a predominance of Engineering, Chemistry, Physics, Computer Science, Materials Science and Mathematics on the research productivity of the two countries as shown in Fig. 13.

[16] (*) 2015-16 Zika epidemic, 2003 SARS epidemic, 2014-2016 Ebola outbreak

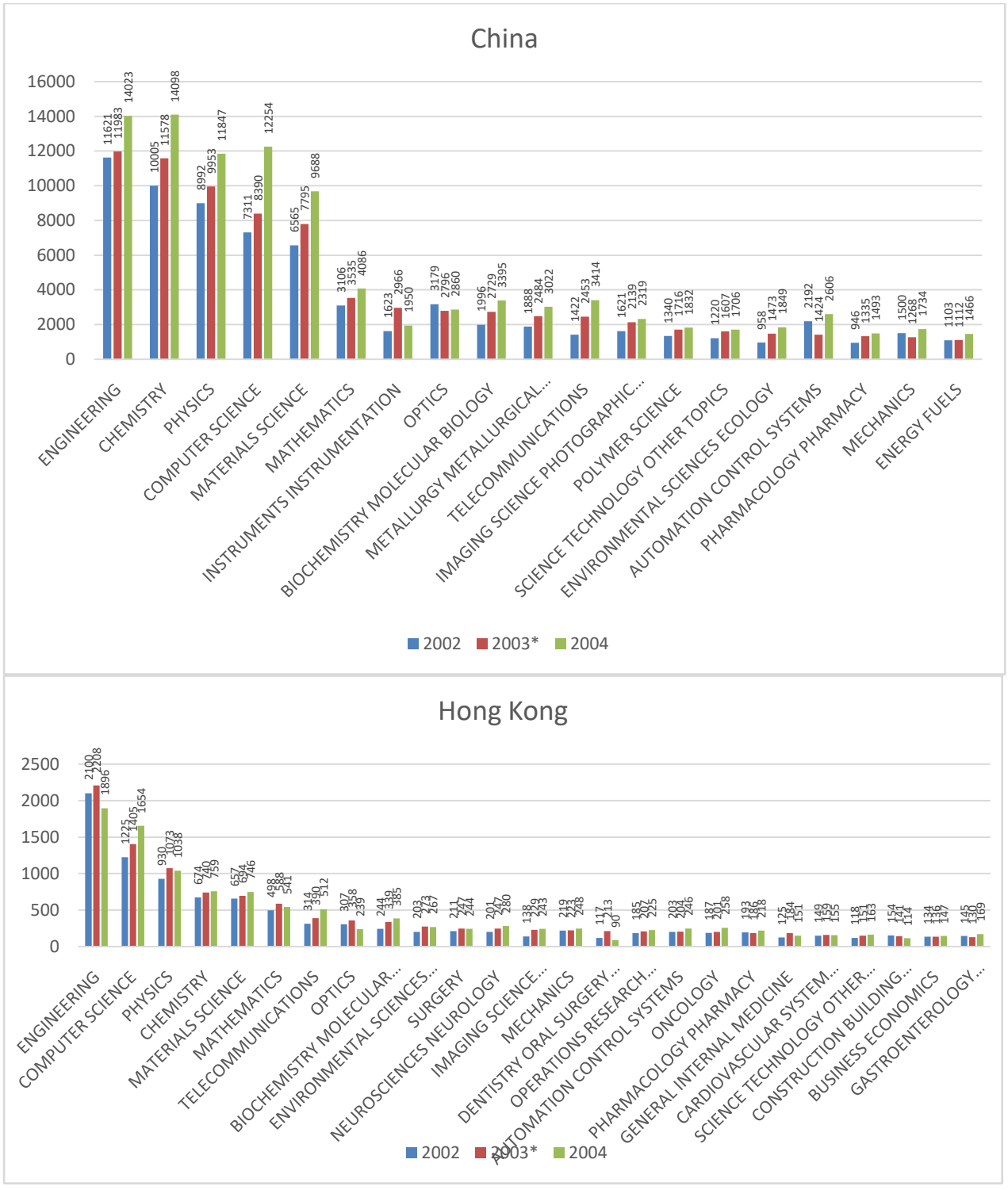


Figure 13: Yearly evolution of the most published research topics for China and Hong Kong during SARS epidemic (*)

This stability of the distribution of research outputs among disciplines has been replicated during Zika outbreak when the contribution of each research area to the research publications of Brazil, Colombia and Puerto Rico kept growing in the same way except for a limited number of new specialties that appeared or largely evolved during the epidemic like Government Law, Social Sciences other topics and Education as shown in Fig. 14.

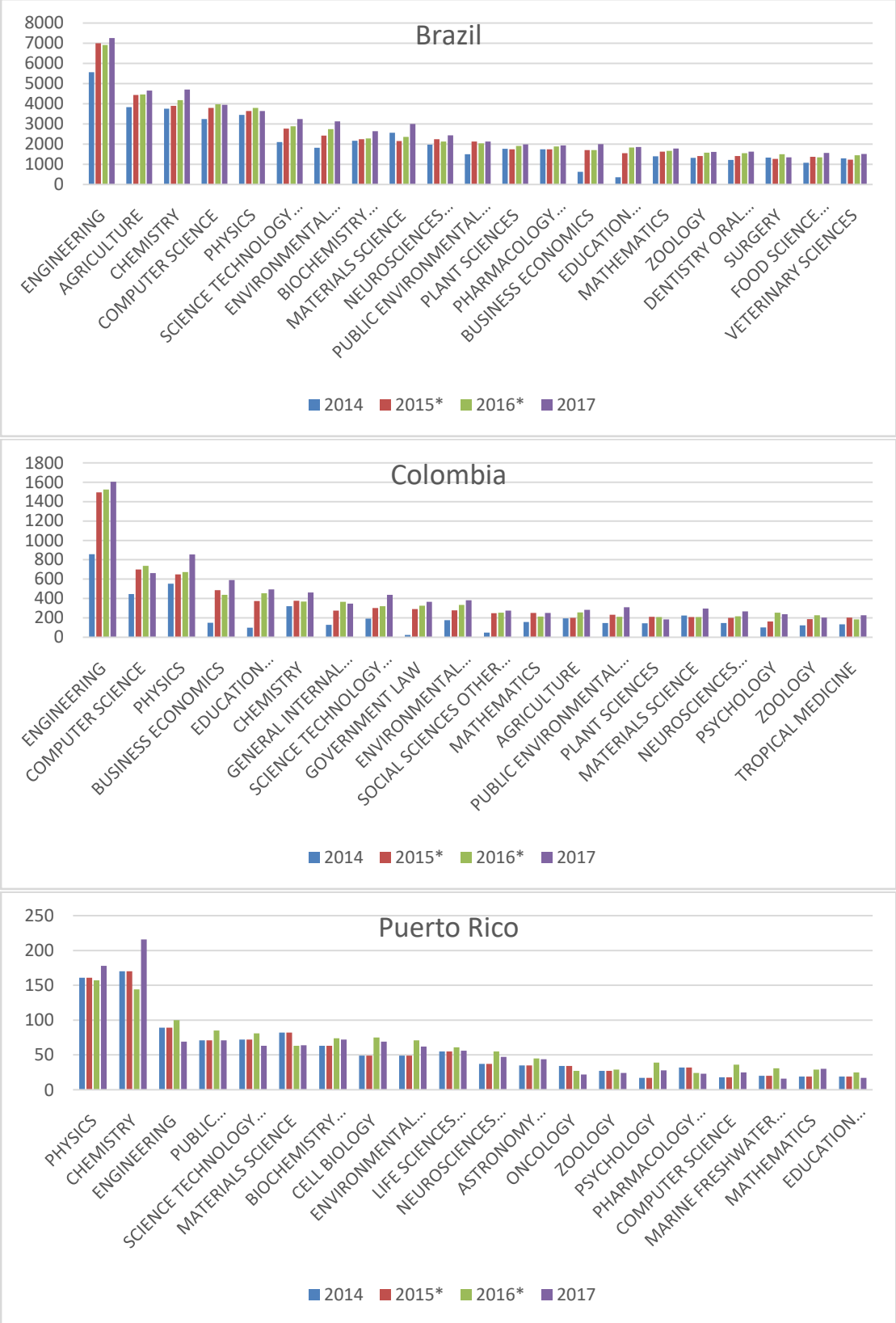


Figure 14: Yearly evolution of the most published research topics for Brazil, Colombia and Puerto Rico during Zika epidemic (*)

Although there is a significant growth of the research output of Guinea and Sierra Leone during the Ebola outbreak, we found that the main research areas of Guinea and Sierra

Leone remained the same with a predominance of research efforts related to infectious diseases, tropical medicine and Public, Environmental and Occupational Health as shown in Fig. 15. Similar to the countries affected by Zika outbreak, we found the appearance or burst of new research areas that are not only linked to Social Sciences (e.g. Business and Economics) but also to biomedical research (Immunology and General Internal Medicine).

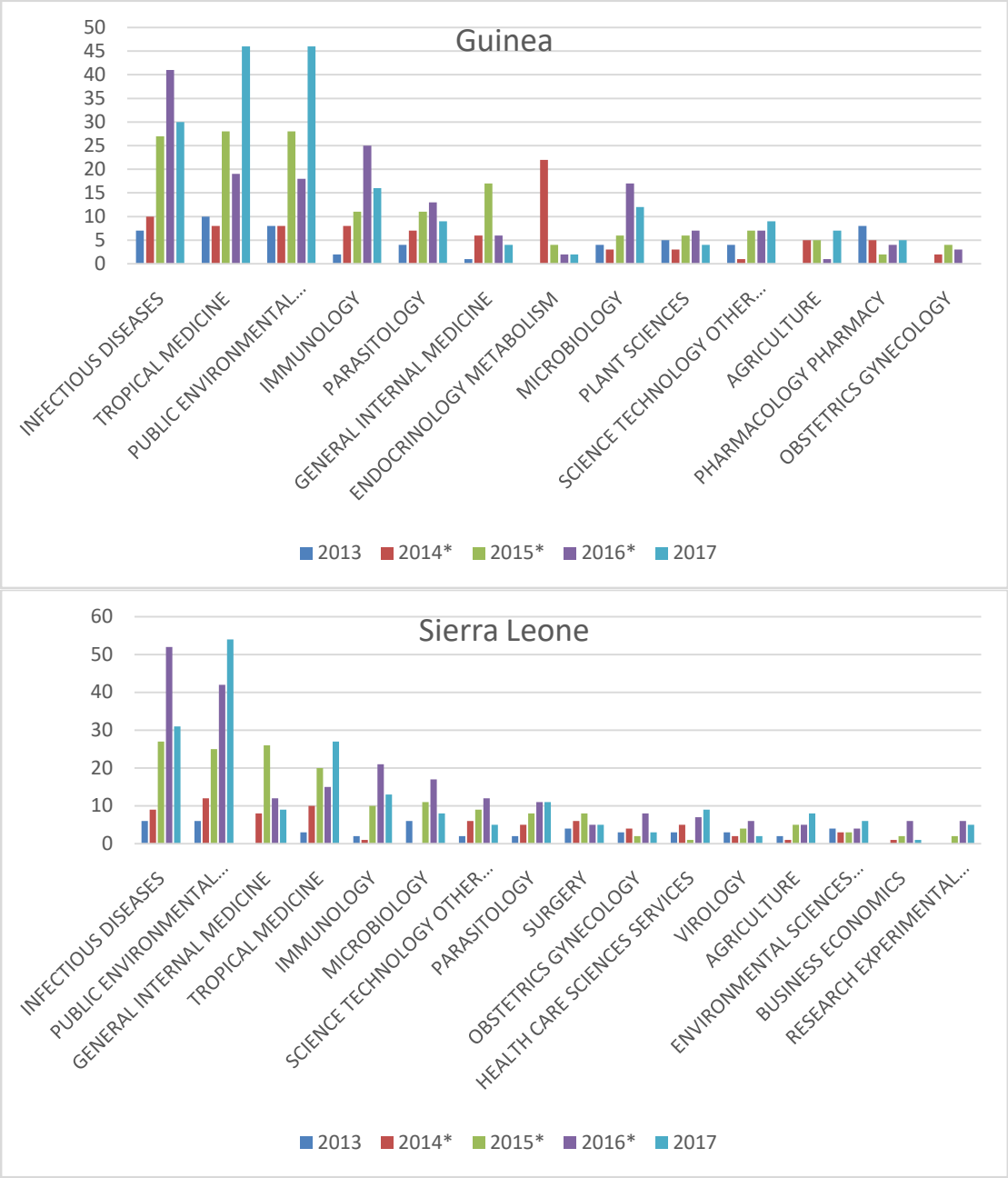


Figure 15: Yearly evolution of the most published research topics for Guinea and Sierra Leone during Ebola outbreak (*)

When observing the scholarly journals mostly publishing the research output of affected countries, we found that most of the journals where local scientists of China and Hong Kong mostly published their works during and after the SARS epidemic are the same ones where they mostly used to publish their work before the outbreak as shown in Fig. 16. These journals explain in part the stability of the research output of these countries during SARS

outbreak and are mainly nationwide research journals (like *Chemical Journal of Chinese Universities – Chinese*, *Acta Physica Sinica* and *Chinese Science Bulletin*), journals mass publishing conference proceedings (like *Proceedings of the SPIE* and *Abstracts of Papers of the American Chemical Society*) or high-impact journals (like *Physical Review E*). We also found that China and Hong Kong tried during the SARS epidemic to target several other journals not mostly covering research of China and Hong Kong like *Rare Metal Materials and Engineering*, *World Journal of Gastroenterology*, *Lecture Notes in Computer Science* and *Journal of Dental Research* for China and *Lancet*, *Chemosphere* and *Journal of Materials Processing Technology* for Hong Kong. Mass publication behaviour to these newly adopted scholarly journals are either maintained or stopped after the epidemic as shown in Fig. 16.

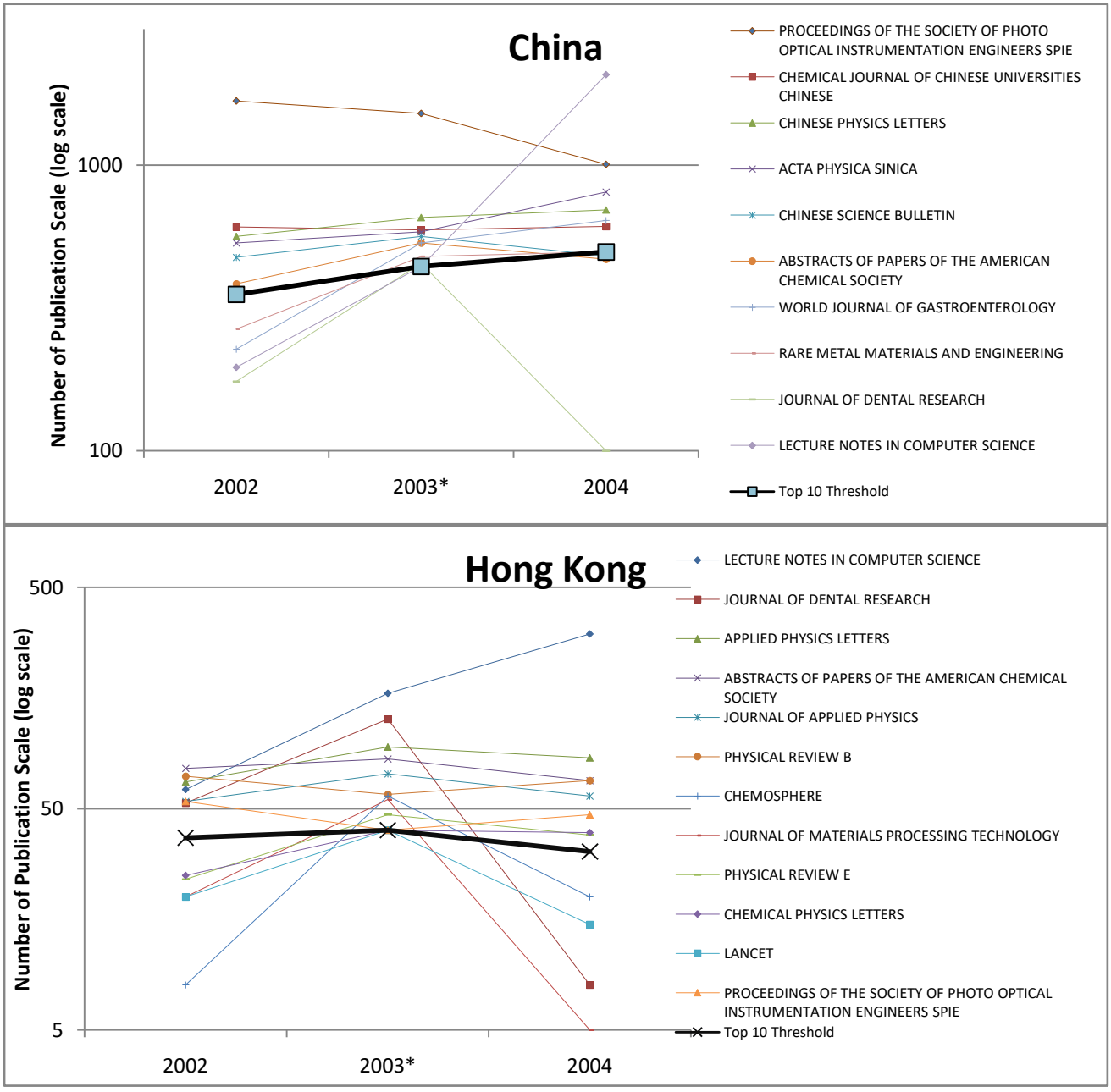
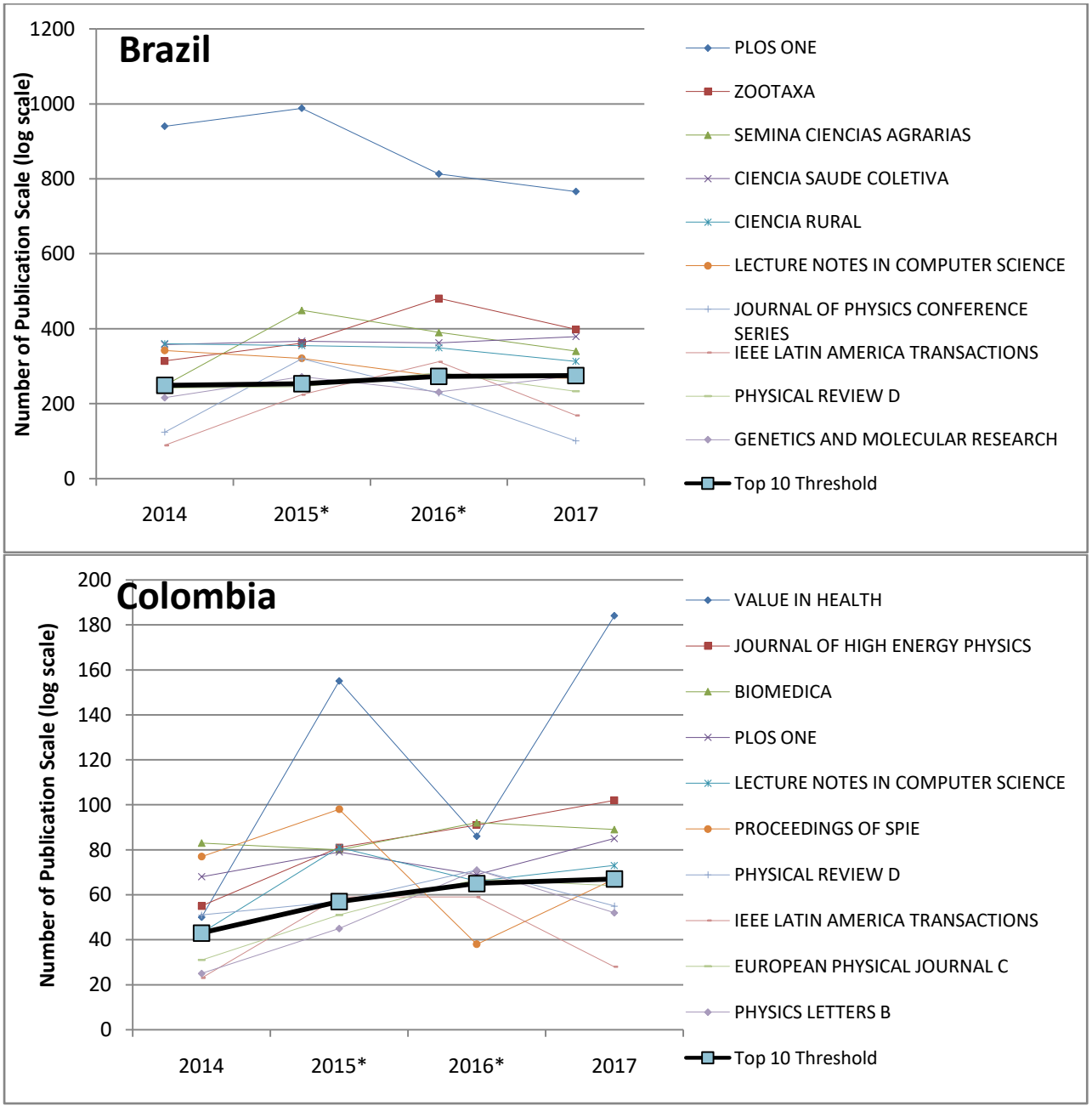


Figure 16: Yearly evolution of the contribution of China and Hong Kong to the scholarly journals mostly publishing the output of these countries during SARS epidemic (*)

The same observation has been found for Brazil, Hong Kong and Puerto Rico during Zika epidemic as shown in Fig. 17. Effectively, most of the journals that publish the research output of these countries during the outbreak that the ones mostly publishing the papers of these nations before and after the epidemic. Similar to China and Hong Kong during SARS epidemic, these stable journals are national or regional research journals (like *Semina Ciencias Agrarias*, *Ciencia Saude Coletiva*, *Ciencia Rural* and *Puerto Rico Health Sciences Journal*), conference proceedings journals (like *Lecture Notes in Computer Science*) or high-impact journals (like *PLoS One* and *Journal of High Energy Physics*). In addition, we found that Brazil, Colombia and Puerto Rico, during the Zika outbreak, aimed to publish in several other journals not mostly covering research of these countries such as *Physics Letters B* and *European Physical Journal C* for Colombia and *IEEE Latin America Transactions* and *Journal of Physics Conference Series* for Brazil. High-scale publication behaviour to these newly adopted research journals are either kept or blocked after the epidemic as shown in Fig. 17.



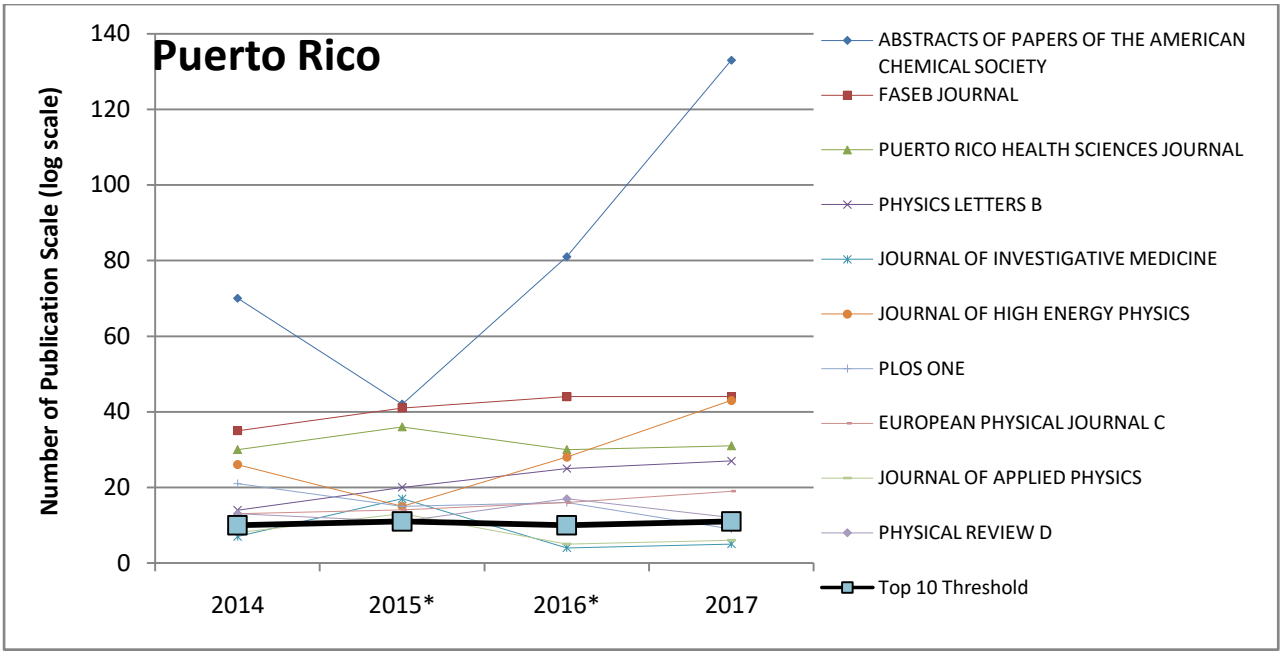
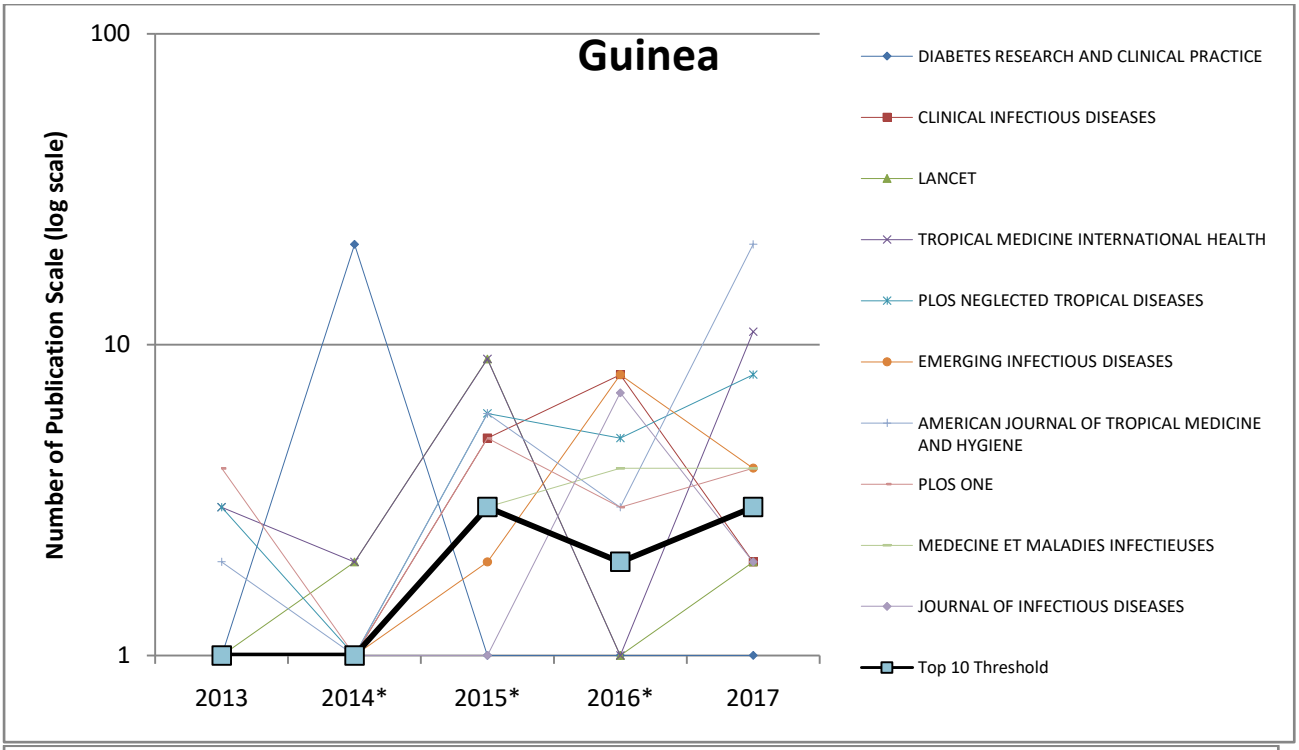


Figure 17: Yearly evolution of the contribution of Brazil, Colombia and Puerto Rico to the scholarly journals mostly publishing the output of these countries during Zika epidemic (*)

Despite the evolution of the research efforts of Guinea and Sierra Leone during Ebola outbreak, we found a similar behaviour of the choice of target journals for mass publication of research papers as China and Hong Kong during SARS epidemic and Brazil, Colombia and Puerto Rico during Zika epidemic with the difference that only some of the target scholarly journals for Guinea and Sierra Leone during the epidemic are the ones mostly aimed by these two countries before and after the epidemic (e.g. PLoS Neglected Tropical Diseases) as shown in Fig. 18. The other journals are mainly ones tried during the epidemic like Diabetes Research and Clinical Practice for Guinea and Lancet Infectious Diseases for Sierra Leone.



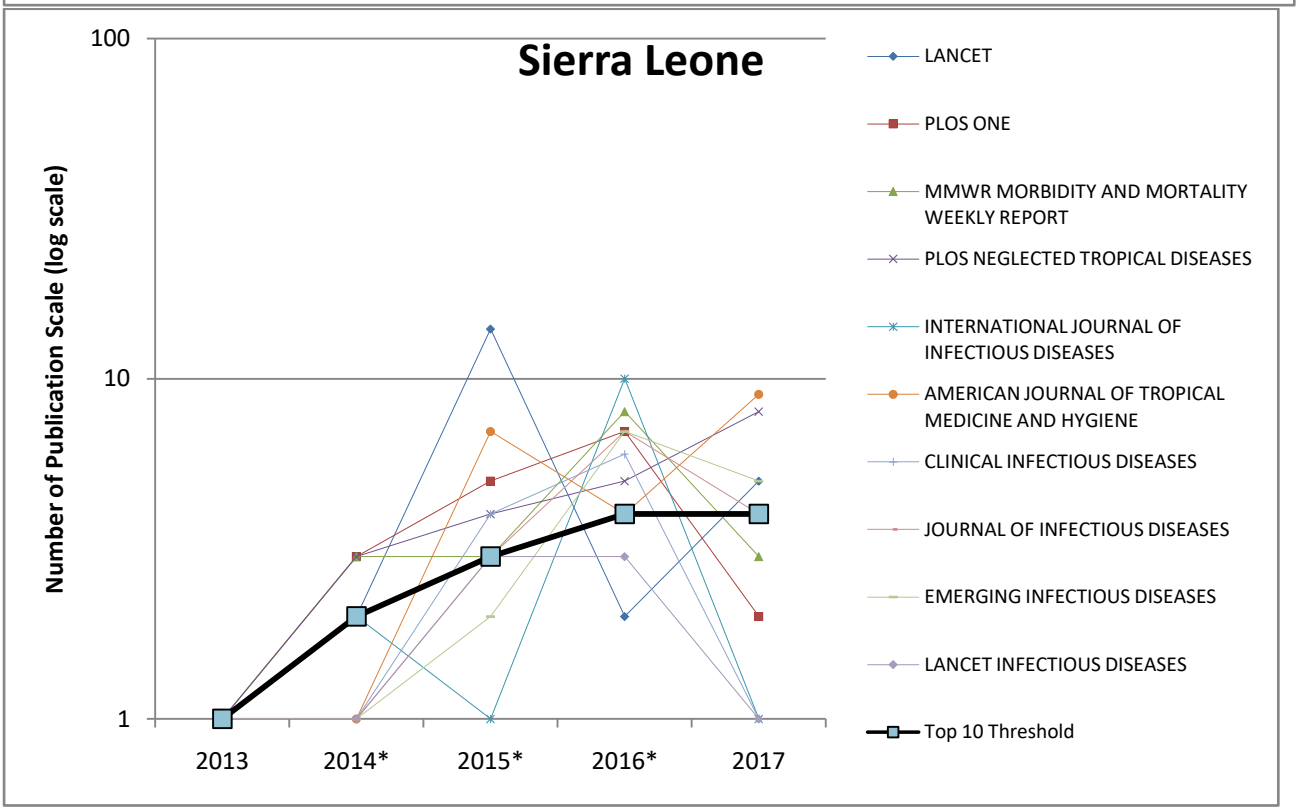


Figure 18: Yearly evolution of the contribution of Guinea and Sierra Leone to the scholarly journals mostly publishing the output of these countries during Ebola epidemic (*)

Discussion

As clearly shown in the patterns of scholarly publishing before epidemics (Figures 1 to 8), we can classify the assessed countries in three categories. The first class is the one of highly

productive research nations and involves China, Hong Kong and Brazil. These countries have robust domestic research productivity and facilities and are not dependent to international research collaborations. The second category is the one of the moderate research countries and involves Colombia and Puerto Rico. This research output is less voluminous and more reliant on international collaborations than the one of the first category. But it is still managed and developed by national institutions and research structures. The third class is the one of underdeveloped research nations and involves Guinea and Sierra Leone. The research output of these countries is quantitatively poor and tightly related to international collaborations. This classification is in accordance with the country standings of Scimago Journal and Country Rank (SJR) where China, Hong Kong and Brazil are among the most productive countries from 1996 to 2018 while Guinea and Sierra Leone are among the least productive countries in the same period as shown in Table 9 [32]. This is also confirmed in other papers that found that Brazil publish more papers and has a more regular and stable implication in worldwide scholarly cooperation than other Latin American countries particularly Colombia [33, 34], that Brazil and China are among the best productive countries worldwide thanks to their robust research policy, collaborations and structures [35, 36] and that least developed research nations such as Guinea and Sierra Leone publish a limited scholarly output not managed by local scientific communities and mostly led by foreign institutions and associations [37].

Table 9: Standings of assessed countries in SJR Country Ranking for their scientific productivity between 1996 and 2018 [32]

World Rank	Country	Publications	h-index
2	China	5901404	794
15	Brazil	938352	530
33	Hong Kong	288889	517
50	Colombia	99301	261
88	Puerto Rico	17160	208
160	Sierra Leone	1128	52
162	Guinea	998	60

During epidemics, it seems that the evolution of the research output of each group has a different behaviour as shown in Figures 1 to 8, in Figures 16 to 18 and in Tables 2 to 8. All of these changes in the characteristics of the research output of affected countries are surprisingly positive though the limited conditions of doing research including travel restrictions [38] and interruption of the work of institutions [39]. While the first group and the second group representing structured research nations have a stability of their global and institutional research productivity and collaborations with minor changes in target journals and research partnerships, the third group representing least developed research nations tends to grow its research productivity during epidemics, significantly change most of its research collaborations and target scholarly journals throughout epidemics, and decrease its high rates of international collaboration at the beginning of outbreaks before increasing them again later. The increase of the research productivity of Brazil, Colombia and Puerto Rico in 2015 is not related to Zika outbreak and is mainly due to the growth of worldwide research output indexed by Web of Science Core Collection as shown in Fig. 19

with the creation of Emerging Sources Citation Index [40]. This index allowed the inclusion of local Latin American journals in Spanish and Portuguese that were not supported before by Web of Science [40]. The slight decrease of international research collaborations in China during SARS epidemic is also not related to the outbreak and is rather affected by a sharp transition in the research collaboration policy of China. Effectively, from 1996 to 2005, China has begun to decrease its interest in collaborating with old and steady partners such as Italy and has tried for years to establish more performing research collaborations with other leading research nations like United States of America [41].

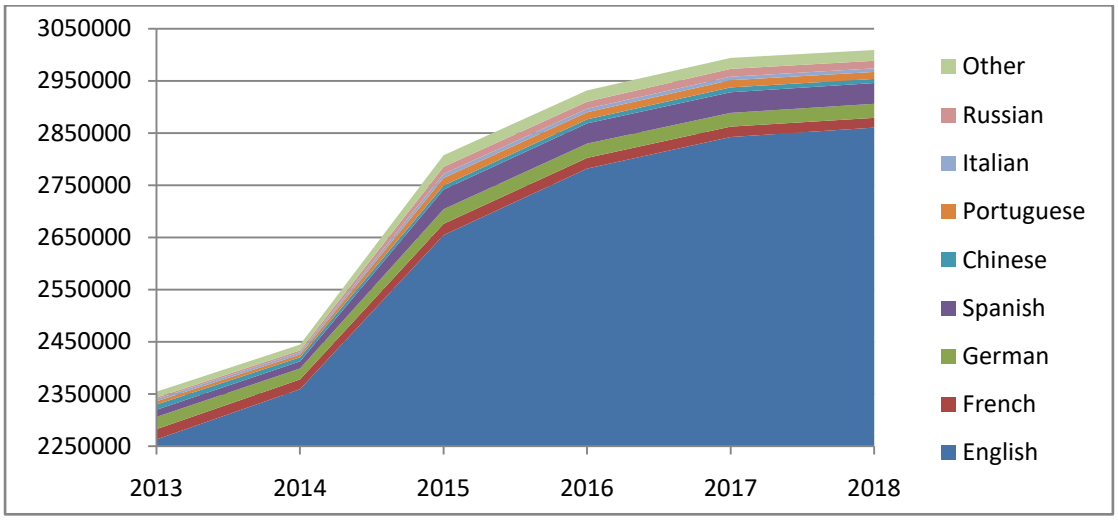


Figure 19: Worldwide productivity and language distribution of research outputs between 2013 and 2018 [30]

The steadiness of the patterns of research productivity for scientifically structured countries is motivated by the technical and corporate development of and the shift to online learning [42] and remote work or telework [6] including online scholarly research efforts, the establishment of long-term and stable international research collaborations [33, 43-44] and of robust scholarly facilities, policy and projects that can remain operational in the period of crisis [34, 45]. As well, this stability can be explained by the absence of impact of epidemics on nationwide research journals representing a significant proportion of the target journals for the countries of the first and second group like *Puerto Rico Health Sciences Journal*, *IEEE Latin America Transactions*, *Seminas Ciencias Agrarias* and *Chinese Science Bulletin* as shown in Figures 16 and 17. In fact, the productivity of these journals does not seem to be highly affected by epidemics although they are mostly issued in affected countries as shown in Fig. 20 [32]. This is mainly explained by the fact that most of the work of editorial boards of scholarly journals is nowadays remotely done thanks to Internet [46].

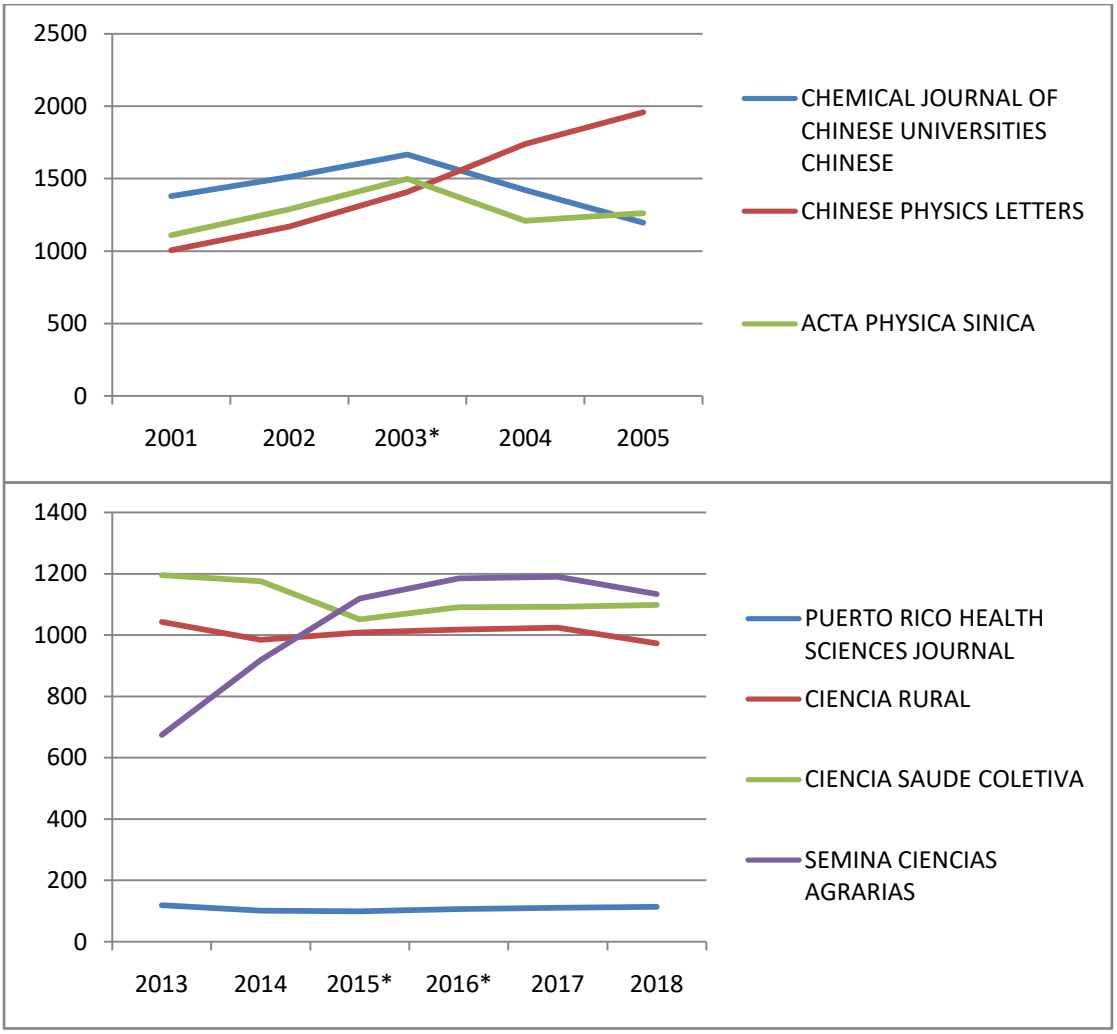


Figure 20 : Productivity of local research journals during epidemics: A) Yearly evolution of the productivity of major Chinese journals between 2001 and 2005[17]. B) Yearly evolution of the productivity of major research journals of Brazil and Puerto Rico between 2013 and 2018[18]

The rise of the research productivity, the short-term decrease of international collaboration rates as well as the change of the characteristics of the research output of underdeveloped research countries during epidemics can be explained by the rescue provided by the international organizations and scientific community to local scientists [47]. Effectively, as international experts cannot travel to affected countries to perform research works due to travel restrictions, international organizations and communities such as World Health Organization offered capacity building trainings allowing elementary local scholars to acquire on-the-ground advanced research skills allowing them to ameliorate the quality of their research outputs in the short term and to lead and conduct short-term research projects without having to collaborate with imposed experts [48]. The later involvement of local scientists from these low-income nations in international high-impact research collaborations by the supportive international organizations explains the later increase of international collaboration rates for these nations [47].

[17] (*) Year of SARS epidemic
[18] (*) Years of Zika epidemic

Although the three groups are heterogenous, we found common characteristics of the behavior of their research outputs during epidemics. Effectively, we found an overall stability of the distribution of the research publications of all countries per language, per publication type and per research area as shown in Figures 9 to 15. This means that there is not an exceptional increase in the rate of biomedical research during epidemics particularly in scientifically structured countries despite the peak of interest in doing research on concerned infections [9-10, 49]. This is intuitively explained by the lack of further recruitment of medical specialists as researchers during epidemics. This is also explained by a steadiness of the interest to the different scientific domains during epidemics as shown by Google Trends during 2019-2020 COVID-19 pandemic in Fig. 21 [50].

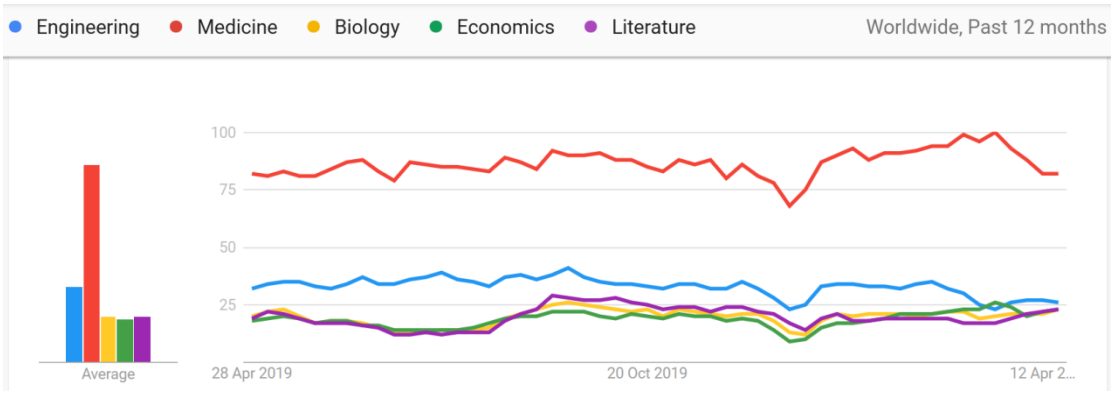


Figure 21: Timely evolution of the interest of Google users to scholarly fields from 28 April 2019 to 28 April 2020 [50]

The advantages of the increase of Internet use during epidemics on the global reach [51] and on the flexibility, speed, health burden and efficiency of professional activities [52] helped reducing or cancelling most of the dreadful effects of transmissible outbreaks on Triple Helix-induced R&D and consequently on the representation of technology-driven research disciplines like Engineering in affected countries. The brief change of the language distribution of the research publications of Brazil, Colombia, Puerto Rico and Guinea between 2014 and 2015 is not due to Zika and Ebola outbreaks but is mainly due to the change of the language distribution of the worldwide research output indexed in Web of Science Core Collection in 2014-2015 (Fig. 19) due to the creation in 2015 of *Emerging Sources Citation Index* that supports more researches in local languages particularly Spanish and Portuguese [40]. The absence of negative effects of outbreaks on the quantity of proceedings papers is mainly due to the enhanced possibility for many people from affected countries to attend and participate to major scholarly and technical events that were not easily reachable thanks to the online setting of such meetings due to travel restrictions caused by epidemics [8]. Furthermore, the emergence of data papers as one of the main publication types for Brazil and Colombia since 2015 is also not related to Zika outbreak and is rather linked to the need of scholarly communities since the early 2010s to publish items about their data sharing to allow research reproducibility and to get credit for their high-scale databases [53, 54]. Moreover, the appearance and growth of Latin American research in several research areas linked to social sciences such as *Education* and *Government Law* during Zika epidemic is not linked to the outbreak and is mostly related to the better indexation of local output in these research areas thanks to *Emerging Sources Citation Index*

that has been created in 2015 [40]. This fact also explains in part the coming out of new research areas like Agriculture and Business Economics for Guinea and Sierra Leone during Ebola outbreak that practically occurred in the same period as Zika outbreak. However, the emergence of several new medical specialties for these two affected countries such as General Internal Medicine, Endocrinology and Immunology during the Ebola epidemic is better explained by the multidisciplinary efforts to study the reasons, mechanisms and consequences of Ebola infectious disease and outbreak [55].

Conclusion

This document aims to provide evidence of the effects of epidemics on the research outputs of countries. It is interesting that the findings point out that the epidemics of the size experienced up to recently did not have adverse effects on the countries' research output. This nonnegative impact of contagious outbreaks goes in line with other positive effects of transmissible epidemics such as the rise of Internet usage. It is a matter of speculation whether there is a threshold above which epidemics and pandemics will have a detrimental effect not only on the economic system of countries but also on the countries' innovation systems. Further investigations on this paradoxical effect of epidemics on scientific research should be done in the context of other nationwide social events like civil wars and famines or in the case of pandemics like COVID-19 where quite all the countries worldwide are affected [6, 56].

Acknowledgements

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