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Evolution and structure of research fields driven by crises and environmental threats: the COVID-19 research

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Abstract
Evolution of science and behavior of new research fields emerging under conditions of crisis are *new topics* hardly known in social studies of science and scientometrics. In particular, the ecosystem and dynamics of research fields during crisis are vital aspects for explaining and planning the scientific development, and allocating resources efficaciously toward positive societal impact. This study here endeavors to analyze the evolution and structure of COVID-19 (Coronavirus Disease 2019) research, a new research field emerged and driven by a global pandemic crisis. The dynamics and structure of this research field are compared to related fields concerning respiratory disorders that are not guided by pandemic crisis, such as chronic obstructive pulmonary disease and lung cancer, to explain similarities and differences. Results suggest that a crisis-driven research field is characterized by an unparalleled velocity of scientific production equal to about 1.2% daily, based on notes and short papers mainly open access that support scientific advances and discoveries in research arena over a short period of time, such as the development of innovative drugs given by novel vaccines and new antiviral COVID-19 treatments. Findings are generalized in properties that clarify the evolution and structure of new research fields and their research behavior in a period of crisis for guiding decisions of policymakers to support scientific and technological progress in human society in the presence of environmental threats.

Keywords COVID-19 · Pandemic crisis · Research fields · Evolution of science · Dynamics of science · Structure of science · Scientific development · Scientific ecosystem · Scientific discovery · Technological change · Crisis management · mRNA vaccine

JEL Classifiction C00 · I10 · O31 · O35 · Z10 · Z19

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Introduction

The evolution and structure of research fields driven by crisis are critical aspects to science and society for allocating resources and planning scientific development efficaciously to support scientific discoveries and new technology having a positive societal impact in the presence of environmental threats (Coccia & Bellitto, 2018; Coccia, 2020a, 2020b, 2020c, 2020d, 2021e; Sun et al., 2013). In this context, the evolution of and ecosystem of scientific research concerning the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) that caused the Coronavirus Disease 2019 (COVID-19) global pandemic can clarify dynamics and characteristics of research fields and their research behavior in conditions of crisis (Bontempi et al., 2021; Bontempi & Coccia, 2021; Boyack et al., 2009; Coccia, 2018a, 2018b, 2020a, 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g, 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g; Dos Santos, 2020; Fanelli & Glänzel, 2013; Fortunato et al., 2018; Sun et al., 2013).

The research questions of this study are:

- How does a new scientific field driven by crisis grow over time compared to established research fields not driven by environmental threats?
- What are the characteristics of research fields under conditions of crises and environmental threats?
- Which areas are major knowledge producers?

This paper confronts these questions here by developing an inductive study focused on scientific documents in COVID-19 research to analyze the evolution and structure of a new research field originated in a period of crisis to explain basic characteristics of scientific development with environmental threats. This study is part of a large body of research that endeavors to explain how scientific fields and new technology emerge and evolve for designing appropriate research policies directed to progress of science in human society (Ardito et al., 2021; Coccia & Bozeman, 2016; Coccia & Wang, 2016; Coccia, 2018a, 2018b, 2020a, 2020b, 2020c, 2020d; Gibbons et al., 1994; Roshani et al., 2021).

Theoretical framework

The investigation of the research field of COVID-19, driven by a global crisis, can clarify how the dynamics of science sustains new knowledge and develops innovations to solve health and social issues that threat nations and global economy (del Rio-Chanona et al., 2020; Di Girolamo & Meursinge Reynders, 2020; Ebadi et al., 2020; Guerrieri et al., 2020). Scholars are investigating different aspects of COVID-19, such as Haghani and Bliemer (2020) that perform a comparative analysis across different epidemics (SARS, MERS and 2019-nCoV) showing that studies focus on epidemic control, chemical constitution of the virus, innovative treatments, vaccines and clinical care. Zhang et al. (2020) also investigate different infectious diseases and show that scholars responded quickly to this public health emergency with an accelerated production of publications in disciplines of virology and immunology. Ebadi et al. (2020) analyze temporal evolution of COVID-19 research through machine learning and show that research communities focus their studies on people with comorbidities. Instead, Di

Girolamo and Meursinge Reynders (2020) investigate characteristics of scientific articles during the initial phase of COVID-19 pandemic crisis and suggest that the majority of early publications on COVID-19 are explorative studies with tentative results. In this research field, Belli et al. (2020) show that international collaboration is growing in all countries to support science advances to cope with COVID-19 pandemic crisis (Coccia & Wang, 2016). Atlasi et al. (2021) confirm that the literature on COVID-19 is increasing with a fast rate of scientific production and higher performance of research labs (cf., Coccia, 2008; Coccia & Rolfo, 2008). New results can be used for an effective management of research and allocation of budgets to novel studies to avoid duplication of information and support the prevention, control, and treatment of COVID-19 (cf., Coccia, 2021f, 2022). Pal (2021) demonstrates that the acceleration of publication growth (given by 1600%) reveals a synergic response of researchers to combat pandemic threat of COVID-19 and its variants. Moreover, many scholarly publishers have disclosed their preprint servers to make publications in this research field available immediately in Open Access platforms to increase the diffusion of science, of new knowledge and of new solutions for COVID-19 pandemic crisis. Moreover, the majority of contributions is in medical sciences, focusing on disciplines of virology, immunology, epidemiology, pharmacology, nursing, etc. The most active academic institutions for scientific production concerning COVID-19 are located in the USA, Canada, France, China, Italy, and the UK (cf., Coccia, 2015a). The advanced countries produced more than 50% of the global research about COVID-19 with a lot of scientific collaborations. Sachini et al. (2021) investigate the evolution of publications in COVID-19 having researchers of Greek institutions, showing a steady increase in publications and research collaborations over time. In addition, results suggest that scientific outputs are mainly driven by higher education and government sectors. At international scale, a significant amount of publications (roughly 20%) is due to countries having "traditionally" major scientific production in the field of medicine.

This study here develops an inductive analysis, which explains as far as possible dynamics of science and underlying relationships of the research field of COVID-19, driven by a pandemic crisis, to understand characteristics of the research behavior in the presence of environmental threats (del Rio-Chanona et al., 2020; Di Girolamo & Meursinge Reynders, 2020; Ebadi et al., 2020; Guerrieri et al., 2020; Xu et al., 2021). The study shows a preliminary comparison of the scientific growth of different pandemics in the initial phase of diffusion to assess the evolutionary path of COVID-19 research. In particular, the study considers the initial growth of publications in COVID-19 compared to:

- Middle East Respiratory Syndrome (MERS) that is a viral respiratory disease caused by a novel coronavirus (CoV) called MERS-CoV, which was first identified in Saudi Arabia in 2012 (WHO, 2021a, b)
- Human Immunodeficiency Virus (HIV) infection and acquired immunodeficiency syndrome (AIDS) that is a spectrum of conditions caused by infection with the retrovirus of HIV. The first case of this infectious disease seems to appear in May 1981 (Sepkowitz, 2001).
- Zika virus disease that is caused by a virus transmitted primarily by Aedes mosquitoes, which bite during the day (WHO, 2021a)
- H1N1 (H1N1pdm09) virus that was detected in the United States in 2009 and spread quickly across the United States and the world. This H1N1 virus contained a unique combination of influenza genes not previously identified in animals or people. This virus was designated as influenza A (H1N1)pdm09 virus (CDC, 2021)

In addition, the paper makes a comparative analysis between the evolution of studies concerning the COVID-19 driven by a pandemic crisis and research fields associated with serious respiratory disorders—such as Chronic Obstructive Pulmonary Disease (COPD) and lung cancer—that are not driven by environmental threats. COPD is defined as a disease state characterized by the presence of airflow obstruction given by chronic bronchitis and emphysema. COPD is a highly prevalent disease affecting more than 10% of the population worldwide. The first manifestations occur at the cellular level with biochemical processes that lead to inflammation (Decramer & Cooper, 2010). COPD generates an accelerated decline in forced expiratory volume in one second (FEV1) over time (Lange et al., 2015). COPD generates a great morbidity and mortality (Halbert et al., 2006; Siafakas et al., 2018). The COVID-19 is also compared to studies in lung cancer: "that forms in tissues of the lung, usually in the cells lining air passages" [as defined by the National Cancer Institute (2021)]. Lung cancer is one of the main diseases in several countries and a leading cause of death worldwide.

The comparative analysis between the evolution of COVID-19 research, which is crisis-driven, and other research fields that are not driven by crises and environmental threats (e.g., COPD and Lung Cancer) can reveal main differences to clarify characteristics and properties of the dynamics of science under conditions of crises to design research policy for efficient allocation of resources directed to discoveries and innovations for a positive impact in science and society (Fig. 1).

Methods and materials

Source and research setting

The study uses data of Scopus (2021) to analyze scientific documents having in title, abstract or keyword the terms connected with respiratory diseases, such as: "COVID", "COPD", and "LUNG CANCER" under study here. Scientific products are appropriate units of analysis that can explain the structure and evolution of science.

Period under study is from 1st April 2020 onwards, using daily data of document results from Scopus (2021). The year 2021 is not considered in some statistical analyses here because the scientific production is ongoing. Moreover, the statistical analyses of trends of research fields under study consider the first published documents and different periods of the scientific evolution, given by:

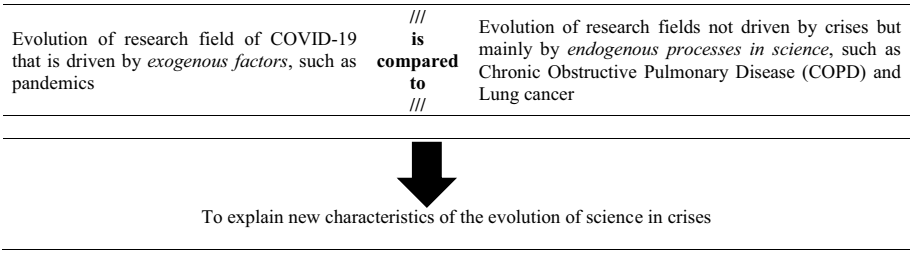

Fig. 1 Structure of the investigation of research fields in a period of crisis

- 1929–2020 for lung cancer
- 1969–2020 for COPD
- and finally, 2019–2020 for COVID-19

Measures

- Accumulation and development of knowledge in research fields under study here (COVID-19, COPD and Lung Cancer) are measured with total document results given by: article, letter, review, note, editorial, conference paper, short survey, book chapter and conference review. In particular, daily data are gathered from April 2020 onwards (Scopus, 2021).
- Documents of research fields under study per subject areas (e.g., medicine, biochemistry, genetics and molecular biology, etc.).
- Document type of research fields under study (i.e., article, letter, conference paper, book chapter, etc.).
- Documents of research fields under study per source title, such as journals.
- Documents of research fields under study per affiliation, such as universities, public and private research labs, hospitals, etc.
- Documents of research fields under study per funding sponsors, such as National Science Foundation, etc.
- Documents of research fields under study per countries.

Data analysis and procedure

- *Question* 1 (evolution of a crisis-driven research field compared to other related fields)

In order to answer the first research question of how a scientific field evolves in a period of crisis compared to established research fields not driven by crisis, the comparative method of inquiry is as follows (cf., Coccia, 2018c).

Methods to explain question 1

Data of documents (in short, Docs) per research fields i (i=COVID-19, COPD and Lung Cancer) are gathered daily from 1st April 2020 to 6th June 2021.

It is calculated the daily growth (%) of documents (Docs) per research field (i) given by:

$$\Delta Docs(\%) \text{ of reserach field } i \text{ (increment)} = \left[\frac{\left(Docs_{dayt} - Docs_{dayt-1}\right)}{Docs_{dayt-1}} \right] \cdot 100 \quad (1)$$

The percent increment is calculated from April 2020 to June 2021 for three research fields (COVID-19, COPD and Lung cancer). Results of COVID-19 are also divided in three periods: from April to July 2020, from August to December 2020 and from January to June 2021 to better assess the different magnitude of the growth of this new research field over time. The data of documents and derived variables are transformed in logarithmic scale to have a normal distribution for appropriate parametric analyses and/or to design graphs and trends with comparable values.

In addition, the study also compares the scientific growth (with publications) of different pandemics in the initial phase of diffusion to assess the evolutionary path of COVID-19 from 2019 to 2021, compared to:

- MERS from $t = 2012$ to $t' = 2015$
- HIV from 1981 to 1984
- Zika virus disease from 2010 to 2016
- H1N1 (H1N1pdm09) virus from 2009 to 2012

The rate of growth is similar to Eq. (1) but it considers documents in the initial year t and year t' as indicated above.

Firstly, preliminary analyses of variables are descriptive statistics based on arithmetic mean and std. error of the mean; coefficients of skewness and kurtosis are applied to assess the normality of distributions and, if necessary, to fix the distribution of variables with a *log*-transformation. Trends and bar graphs of research fields under study can show the type of scientific development and annual increment over 2020–2021 period in a context of comparative analysis.

Secondly, the study analyses the evolution of documents as a function of time. The specification of relationship is based on a linear model:

$$\text{Linear model}: y_i = b_0 + (b_1 t) + e \tag{2}$$

y = scientific documents in the research field i (i = COVID-19, COPD, Lung Cancer)

t = *time* = progressive series indicating the time from 1 (1st day), 2 (2nd day), …, to 420 (420 day)

b_0 = constant

b_1 = coefficient of regression

ε = error term

Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of models [2] in regression analysis.

Thirdly, the study analyses whether the difference of arithmetic mean (formula [1]) between data of research fields considered as independent groups is significant (e.g., COVID-19 = group 1 that is driven by crisis vs. COPD = group 2, which is not driven by crisis, etc.). In particular, the Independent Samples *t*-Test is applied to compare the means of two independent groups to determine whether there is statistical evidence that the associated population means are significantly different. The Independent Samples *t*-Test requires the assumption of homogeneity of variance—i.e., both groups have the same variance and as a consequence Levene's Test is performed. After that, null hypothesis (H_0) and alternative hypothesis (H_1) of the Independent Samples *t*-Test are:

H_0: $\mu_1 = \mu_2$, the two population means are equal in groups.

H_1: $\mu_1 \neq \mu_2$, the two population means are *not* equal in groups.

The arithmetic mean of groups is compared considering pair of research fields under study as follows:

- COVID-19 (group 1)—COPD (group 2)
- COVID-19 (group 1)—Lung Cancer (group 3)
- and COPD (group 2)—Lung Cancer (group 3)

Remark. Group 1 indicates a crisis-driven research field; Groups 2 and 3 are research fields not driven by crises but by endogenous factors of the science dynamics (e.g., collaboration, etc.).

This analysis is performed considering data from April to December 2020 for 260 days to assess the differences between means in the initial evolution of COVID-19 research to obtain stable results. Data of 2021 are not considered in this analysis because they are ongoing.

- *Question* 2 and 3 (characteristics of crisis-driven research fields and research behavior in a period of crisis)

In order to clarify the second and third question concerning main drivers and characteristics of the research field of COVID-19, the method is as follows.

Methods to clarify question 2 and 3

Data analysis procedure here uses total number of documents published in the research field of COVID-19 from April to December 2020 and from January to June 2021 to assess variations of research behavior in a period of crisis considering:

- Main research areas supporting the evolution of the research field of COVID-19
- Leading journals supporting the evolution of the COVID-19 research
- The most prolific institutions in the production of COVID-19 research
- The most important institutions that have funded studies in the research field of COVID-19
- Finally, a ranking of the most prolific countries in COVID-19 research that have supported scientific and technological advances.

Statistical analyses are performed with the Statistics Software SPSS® version 26.

Results

Dynamics of the research field driven by crisis compared to other research fields (question 1)

Pandemic is a very special condition of crisis in society that it affects the behavior and characteristics of scientific activity. First of all, the study here shows a comparison of the scientific production growth of different pandemics in the initial phase of diffusion to assess the evolutionary path of COVID-19 research and of other infectious diseases. In particular, the study considers the initial growth of publications in COVID-19 research compared to Middle East Respiratory Syndrome (MERS) from 2012 to 2015, HIV from 1981 to 1984, Zika virus disease from 2010 to 2016 and H1N1pdm09 virus from 2009 to 2012. Figure 2 suggests the unparalleled growth of publications in COVID-19 research, likely associated with the high number of deaths that has supported a lot of scientific research to solve this global pandemic crisis (cf., Pal, 2021).

Figure 3 shows the evolution of research fields, in which COVID-19 research with a crisis-driven origin in 2019 is compared to research field of lung cancer started in 1929

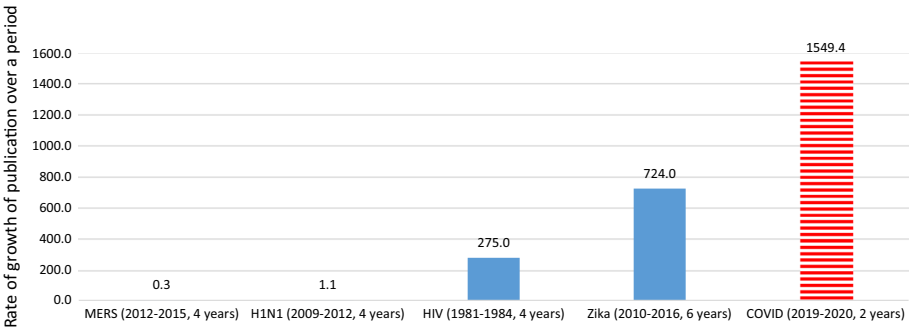

Fig. 2 Rate of growth of publications concerning some pandemics in the initial phase of diffusion

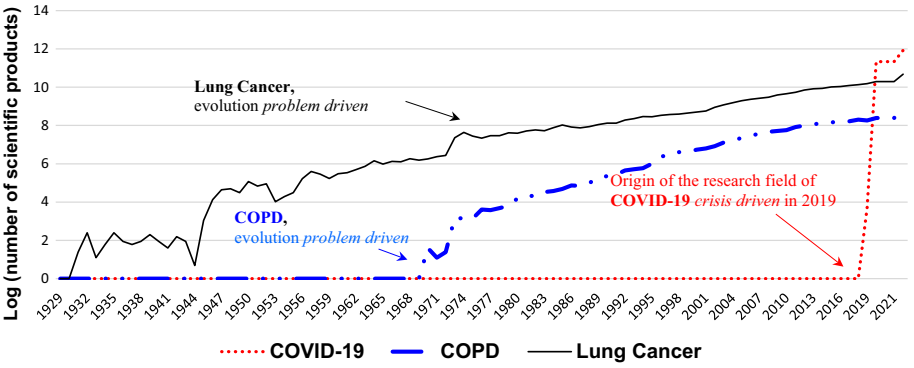

Fig. 3 Evolution of crisis- and problem- driven research fields over time (at 6 June 2021). Note: *Log* scale is to have comparable trends

(though some occasional previous papers) and COPD originated in 1969 or thereabouts. Results suggest two different types of evolution of research fields:

- *crisis-driven evolution* is associated with exogenous factors that generate shocks and environmental threats in socioeconomic systems and need to be solved as soon as possible. These research fields (e.g., COVID-19) have an accelerated growth.
- *problem-driven evolution* is associated with factors of normal science based on consequential problems concerning people and environment that need to be solved. These research fields have a steady-state and linear growth over time (e.g., studies in COPD and lung cancer).

Results show that the evolution of research fields in COPD and lung cancer, originated because of main diseases in society (problem-driven origin), has a linear development (arithmetic growth) of publications (y) given by equation $y(t) = \alpha + \beta t$ with an acceleration for lung cancer from 1975 (about 45 years after its origin in 1929) and for COPD from 1995 (25 years after the origin); instead, crisis-driven research field of COVID-19 originated with a global pandemic threat has an evolutionary paths similar to an exponential development of publications: $y(t) = \alpha \cdot e^{\beta t}$ (cf. also Fig. 4).

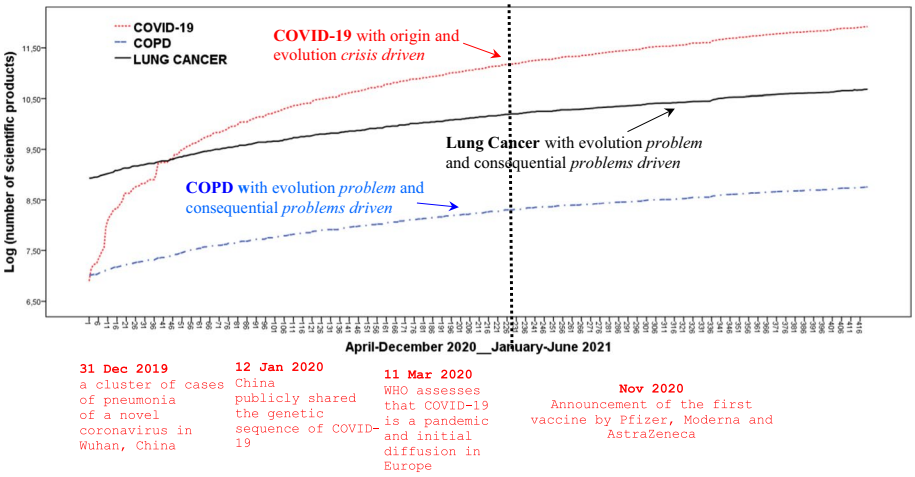

Fig. 4 Evolution of COVID-19 research compared to COPD and Lung Cancer ($t = 420$ days from April to December 2020 and from January to June 6th, 2021). COVID-19 = Coronavirus Disease 2019; COPD = Chronic Obstructive Pulmonary Disease; *Log* scale is to have comparable trends

Figure 4 shows the initial evolution of the research field of COVID-19 with some chronological events given by the first cases in China (year 2019), the alarming levels of spread and severity in Europe from March 2020 and the announcement of first vaccines in November 2020.

Table 1 considers the initial number of publications in COVID-19, COPD and lung cancer research (first three years since origin). It is important to observe that the annual scientific production of COVID-19 studies in December 2020 (i.e., 83,621 documents) has surpassed annual production of main research fields, such as COPD having 4397 documents and in particular lung cancer having 29,362 documents.

Table 2 confirms the unparalleled evolution of the research field of COVID-19 compared to lung cancer and COPD. In particular, in April 2020 the research field of COVID-19 was at the initial stage of evolution and had the lowest number of publications, whereas in June 2021 it has outclassed over other research fields (COPD and Lung Cancer) that have had a stable evolution over time. In fact, the average growth of the research field of COVID-19 is + 1.2% daily from April 2020 to June2021, whereas other research fields have had a normal evolution given by a steady growth equal to about + 0.42% of daily publications (cf., Fig. 5). In addition, Table 2 shows that the evolution of the research field of COVID-19 from April to July 2020 had an average growth of + 3.16% daily, whereas from

Table 1 Number of publications of research fields in the first three years after their origin

Year	COVID-19	Year	COPD	Year	Lung cancer
2019	57	1969	1	1929	1
2020	85,539	1970	5	1930	0
2021	on going	1971	3	1931	4
		2020	4,397	2020	29,362

Data refer to 6th June 2021 (Scopus, 2021)

Table 2 Descriptive statistics of scientific documents in the research fields of COVID-19, COPD and Lung Cancer based on 420 days from April 2020 to June 6th, 2021

Variables	Arithmetic Mean	Std. Error
COVID-19, documents (Docs)	68,067.61	2,135.79
COPD, documents	3,743.23	74.32
Lung Cancer, documents	25,119,04	504.17
Δ*Docs*(%)*of* COVID-19, daily increment April 2020 to June2021	1.19	0.16
Δ*Docs*(%)*of* COPD, daily increment April 2020 to June2021	0.417	0.024
Δ*Docs*(%)*of* Lung Cancer, daily increment April 2020 to June2021	0.419	0.023
Δ*Docs*(%)*of* COVID-19, daily increment April-July 2020	3.16	0.56
Δ*Docs*(%)*of* COVID-19, daily increment August-December 2020	0.65	0.06
Δ*Docs*(%)*of* COVID-19, daily increment January-June 2021	0.38	0.04

COVID-19 = Coronavirus Disease 2019; COPD = Chronic Obstructive Pulmonary Disease

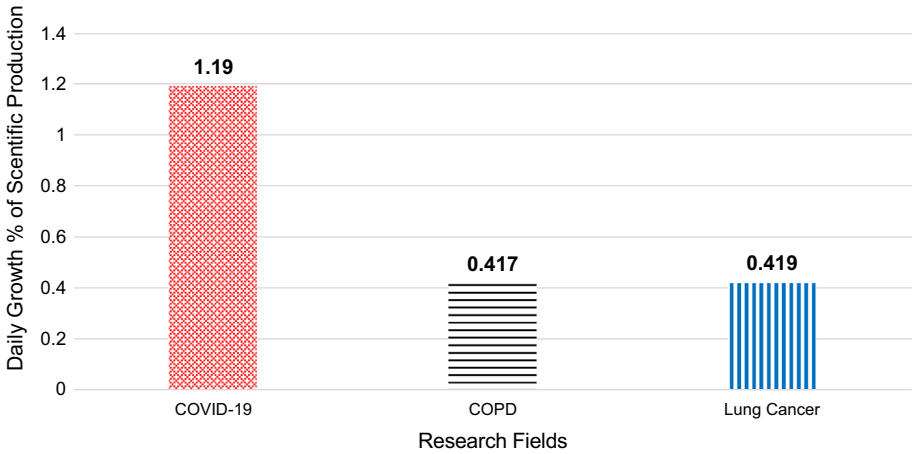

Fig. 5 Daily growth (%) of scientific production of research fields based on 420 days from April 2020 to June 6th 2021. COVID-19 = Coronavirus Disease 2019; COPD = Chronic Obstructive Pulmonary Disease

August to December 2020 has reduced the acceleration of scientific production, converging towards a more stable growth of about + 0.65% daily; in the 2021 (January-June 2021 period) the growth is + about 0.38%, showing a cycle of life that is directed towards a phase of maturity.

Table 3 suggests that in the research field of COVID-19, an increase of 1 day, it increases the expected number of publications by about 360 units (p-value < 0.001), whereas in the research field of COPD by about 13 units (p-value < 0.001), finally in the research field of Lung Cancer, the expected number of publications increases by about 85 units (p-value < 0.001). This result confirms the unparalleled growth of scientific production in the research field of COVID-19. Finally, the Independent Samples t-Test compares the means of two independent groups in order to determine whether there is statistical evidence that the associated population means of ΔDocs (from April to December 2020) are significantly different (2021 is excluded in this statistical analysis because the research field

Table 3 Parametric estimates of the relationship of scientific production in research fields as function of time ($T=420$ days, from April 2020 to June 2021)

	Model linear COVID-19	Model linear COPD	Model linear lung cancer
Constant α	−7619.01***	1102.74***	7209.64***
(St. Err.)	(323.46)	(3.78)	(30.34)
Coefficientβ *(time)* (St. Err.)	359.56*** [a] (1.33)	12.54*** [a] (.016)	85.08*** [a] (.13)
F	72,915.44***	651,540.61***	464,061.02***
R^2	.994	0.99	.99

***p-value < 0.001

a = predictor is a progressive series (N) indicating the time from 1 (1st day), 2 (2nd day) … to 420 (420th day) from April 2020 to 6th June 2021

of COVID-19 is ongoing). The p-value of Levene's test is significant, and we have to reject the null hypothesis and conclude that variances in groups under study are significantly different (i.e., Equal variances are not assumed), except arithmetic mean of $\Delta Docs(\%)$ between COPD and LC that has p-value < 0.27 and as a consequence Equal variances are assumed (Table 4).

Table 4 shows that:

- There was a significant difference in mean $\Delta Docs(\%)$ between research fields of COVID-19 and COPD ($t_{264.809}=4.69$, $p<0.001$), suggesting a *different* evolution of research fields associated with crisis- and problem-driven factors.
- There was a significant difference in mean $\Delta Docs(\%)$ between research fields of COVID-19 and Lung cancer ($t_{263.118}=4.727$ $p<0.001$), also suggesting a *different* evolution of these research fields associated with crisis- and problem-driven factors.
- Whereas, arithmetic mean of $\Delta Docs(\%)$ between research fields of COPD and Lung cancer is not different but it is rather similar ($t_{505.496}=0.161$ $p<0.872$), suggesting a *similar* evolution of these research fields that are not driven by crisis but both by endogenous factors to science.

The conclusion of these statistical analyses is that the rate of evolutionary growth of the research field of COVID-19 (crisis-driven) is statistically different from other research fields, such as COPD and Lung cancer (based on problem-driven factors). Hence, crisis-driven research field of COVID-19 has an accelerated and disproportionate growth compared to problem-driven research fields with the potential to lead to manifold scientific and technological breakthroughs in a short period of time.

Results to explain the second and third research question on characteristics of research field and on research behavior in the presence of turbulent crisis

The evolution of the crisis-driven research field of COVID-19 reveals some characteristics to understand the dynamics of science and research behavior in a period of crisis. The most productive research areas in the research field of COVID-19 are mainly related to life science (Table 5). Of the top 10 research areas, more than 53% of documents published on COVID-19 research is in medicine; biochemistry; genetics and molecular biology has more

Table 4 Independent samples test

		Levene's Test for equality of variances		*t*-test for equality of Means				
		F	Sig	*t*	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Δ*Docs*(%), COVID-19/COPD	Equal variances assumed	35.53	0.001	4.690	510	0.001	1.186	.2528
	Equal variances not assumed			4.690	264.809	0.001	1.186	.2528
Δ*Docs*(%), COVID-19/LC	Equal variances assumed	37.28	0.001	4.727	510	0.001	1.194	.2524
	Equal variances not assumed			4.727	263.118	0.001	1.194	.2524
Δ*Docs*(%), COPD/LC	Equal variances assumed	1.204	0.273	.161	510	.872	.00758	.0470
	Equal variances not assumed			.161	505.496	.872	.00758	.0470

$N = 256$ days over April-December 2020 period. Δ = increment; Docs = documents

Table 5 Top ten areas supporting the evolution of the research field of COVID-19

Ranking	31 December 2020 Documents published, Disciplines	*N*	%	6 June 2021 Documents published, Disciplines	*N*	%
1	Medicine	57,842	57.62	Medicine	97,236	53.36
2	Social sciences	9377	9.34	Social sciences	19,210	10.54
3	Biochemistry, Genetics and molecular biology	8560	8.53	Biochemistry, Genetics and molecular biology	15,045	8.26
4	Immunology and Microbiology	5472	5.45	Immunology and Microbiology	9568	5.25
5	Nursing	3723	3.71	Computer science	8401	4.61
6	Pharmacology, Toxicology and Pharmaceutics	3554	3.54	Environmental sciences	7444	4.09
7	Environmental sciences	3502	3.49	Nursing	6936	3.81
8	computer science	3054	3.04	Engineering	6679	3.67
9	Engineering	2819	2.81	Pharmacology, Toxicology and Pharmaceutics	6058	3.32
10	Neuroscience	2480	2.47	Psychology	5646	3.10
	Total	100,383	100.00		182,223	100.00

than 8%, and immunology and microbiology has more than 5% (cf., Zhang et al., 2020). In the top ten areas, there is also social sciences (more than 9%) and environmental science (about 3.5%) because manifold studies analyze possible relations between ecology of the COVID-19, environment and society (Coccia, 2020a). The comparison of two periods in 2020 and 2021 shows the growth of computer science in 2021 (associated with simulation models of pandemic diffusion) and of psychology likely associated with side effects of containment policies on mental health of population (Coccia, 2021a). This research field of COVID-19 confirms the properties of science dynamics by Coccia (2018a, b) that the emergence of a research field is in critical (parent) disciplines (e.g., medicine, biochemistry, genetics and molecular biology in the case study of COVID-19), and subsequently the evolution is driven mainly by few disciplines (3–5) that generate more than 80% of documents (*concentration of scientific production).*

Table 6 shows the top ten journals that have published more contributions in the COVID-19 research. Five of the top ten journals are related to medicine (parent discipline; cf. Coccia, 2018a, 2018b). In the top ten, there are also journals related to environmental and sustainability science for investigating relationships between environmental pollution and the spread of COVID-19 (cf., also Coccia, 2020a, b, 2021b, 2021c, 2021d, 2021f, 2022; Zhang et al., 2020). In the top ten, it is also important to note the presence of the journal "Medical Hypothesis" because in the initial phase of pandemic crisis generated by a novel coronavirus hardly known, a lot of scholars suggest multiple working hypotheses (cf., Coccia, 2018c) to explain likely determinants of transmission dynamics, effective treatments and policy responses to reduce the negative impact of COVID-19 pandemic in society (cf. also, Haghani & Bliemer, 2020). The evolution of this research field in 2021, compared to 2020, is also driven by journals of psychology and interdisciplinary periodicals (e.g., Scientific Reports) that enter in the top ten list having a higher number of contributions.

The most prolific institutions in the COVID-19 research are Harvard Medical School and Chinese academic organizations (e.g., Huazhong University of Science and Technology, and Tongji Medical College). In the year 2021, University of Toronto and INSERM play a main role in the scientific production. The top 10 active institutions in COVID-19 research are mainly academic institutions of advanced countries: 1 in the USA, 2 in China, 3 in England, 2 in Italy, 1 in France and 1 in Canada (Table 7).

The top ten funding organizations that have supported the COVID-19 research are located in the USA, China, the UK, Europe (with European Commission) and Brazil. In particular, at December 2020, institutions in the USA have funded about 43% of published studies among top ten institutions, in China about 35% of total top ten, in the UK roughly 12.5% of studies and finally in Brazil about 9%. In June 2021, funding role of US institutions is reinforced in the top ten with about 47%, China, UK and Brazil have a slightly reduction. In 2021, a supranational institution given by European commission enters in the top ten of funding institutions with about 6%. Results also show that the top funding institutions in scientific production of COVID-19 are mainly public organizations, except Wellcome Trust that is a global charitable foundation located in London (UK). In particular, Table 8 shows the driving role of public funding organizations in two large countries given by the USA and China that have funded more than 78% of documents on COVID research among top ten institutions (cf., also Zhang et al., 2020). De Roeck (2016) argues that scientific discovery is also due to main role of funding of governments and funding agencies. In fact, these countries (the USA and China) have developed the first COVID-19 vaccines.

The evolution of research field of COVID-19 is driven mainly by scientific production in advanced and rich countries that have published about 78% of documents; the list

Table 6 Top ten journals leading the evolution of the research field of COVID-19

Ranking	31 December 2020 Documents published in Journals	*N*	%	6 June 2021 Documents published in Journals	*N*	%
1	International Journal of environmental research and public health	737	14.87	International Journal of environmental research and public health	1702	18.43
2	Journal of medical virology	648	13.07	Plos ONE	1465	15.87
3	BMJ Clinical research from British Medical Association	615	12.41	Journal of medical virology	1025	11.10
4	BMJ from British Medical Association	576	11.62	BMJ	896	9.70
5	Plos ONE	562	11.34	BMJ Clinical research	875	9.48
6	Lancet	413	8.33	Sustainability (Switzerland)	719	7.79
7	International Journal of Infectious diseases	399	8.05	International Journal of Infectious diseases	670	7.26
8	Medical Hypotheses	354	7.14	Scientific Reports	658	7.13
9	Science of the total environment	327	6.60	Frontiers in Psychology	630	6.82
10	Sustainability	326	6.58	Lancet	594	6.43
	Total	4957	100.00		9234	100.00

Table 7 The top ten prolific institutions in the production of COVID-19 research

Ranking	31 December 2020 Documents published, Research Institutions/Affiliations	*N*	%	6 June 2021, Documents published Research Institutions/Affiliations	*N*	%
1	Harvard Medical School, USA	1422	15.56	Harvard medical school	2325	15.76
2	Huazhong University of Science and Technology, China	1111	12.16	Huazhong University of Science and Technology	1591	10.78
3	Tongji Medical College, China	1056	11.56	University of Toronto	1579	10.70
4	The Institut national de la santé et de la recherche médicale, INSERM, the French National Institute of Health and Medical Research	983	10.76	INSERM, France	1508	10.22
5	University of Toronto, Canada	908	9.94	Tongji Medical College	1477	10.01
6	Università degli Studi di Milano, Italy	776	8.49	University of Oxford	1395	9.45
7	University of Oxford, England	761	8.33	University College London	1289	8.74
8	Università di Roma la Sapienza, Italy	755	8.26	Imperial College London	1223	8.29
9	University College London, England	704	7.71	Università degli Studi di Milano	1209	8.19
10	Massachusetts General Hospital, USA	660	7.22	Università di Roma La Sapienza	1159	7.85
	Total	9136	100.00		14,755	100.00

Table 8 Top ten institutions that have funded studies in the research field of COVID-19

Ranking	31 December 2020 Documents/studies funded by	*N*	%	6 June 2021 Documents/studies funded by	*N*	%
1	National Natural Science Foundation of China	1901	30.84	National Institutes of Health, USA	3992	27.01
2	National Institutes of Health, USA	1641	26.62	National Natural Science Foundation of China	3689	24.96
3	National institute for health research, UK	422	6.85	U.S. Department of health and human services	1140	7.71
4	National Science Foundation, USA	411	6.67	National institute for health research, UK	1005	6.80
5	Wellcome Trust, UK	346	5.61	National Science Foundation, USA	963	6.52
6	National Institute of allergy and infectious disease, USA	344	5.58	National Key research and Devel program of China	912	6.17
7	Conselho nacional desenvolvimento Cient, Brazil	326	5.29	European Commission	881	5.96
8	Fundamental Research Funds for the Central Universities, China	277	4.49	National Institute of Allergy and infectious disease, USA	816	5.52
9	National heart, Lung and Blood institute, USA	256	4.15	Wellcome Trust, UK	709	4.80
10	Coordenecao de aperfeicoamento de pessoal de Nivel Superior, Brazil	240	3.89	Conselho nacional desenvolvimento Cient, Brazil	672	4.55
	Total	6164	100.00		14,779	100.00

Table 9 Top ten countries with the highest number of documents produced in the research field of COVID-19

Ranking	31 December 2020 Countries of production	*N*	%	6 June 2021 Countries of production	*N*	%
1	United States	21,285	30.37	United States	38,155	31.06
2	China	9293	13.26	United Kingdom	15,975	13.01
3	United Kingdom	9004	12.85	China	15,092	12.29
4	Italy	7765	11.08	Italy	12,664	10.31
5	India	5885	8.40	India	10,654	8.67
6	Spain	3585	5.11	Spain	6505	5.30
7	Canada	3542	5.05	Canada	6357	5.18
8	Germany	3274	4.67	Germany	6227	5.07
9	France	3253	4.64	Australia	5718	4.65
10	Australia	3209	4.58	France	5489	4.47
	Total	70,095	100.00		122,836	100.00

Table 10 Characteristics of publication in crisis-driven (COVID-19) research and not crisis-driven research fields (COPD and Lung Cancer), using data on 6th June 2021

	COVID		COPD		Lung cancer	
	Number	% of total	Number	% of total	Number	% of total
Total publication June 2021	152,970		60,798		449,875	
Open access	116,203	75.96	24,616	40.49	162,703	36.17
Type of documents						
Article	93,563	61.16	44,039	72.43	333,986	74.24
Letter	18,201	11.90	1281	2.11	13,089	2.91
Review	16,795	10.98	8645	14.22	55,782	12.40
Note	8769	5.73	1227	2.02	8643	1.92
Conference	307	0.20	2256	3.71	13,800	3.07

of top ten countries also includes China with about 13% and India with 8% (Table 9). This result further confirms the concentration of scientific production in specific geo-economic areas given by rich countries (Coccia, 2018a, b). Coccia (2019a, b, c) argues that nations produce science advances and new technology to endorse a socio-economic power and leadership directed to take advantage of important opportunities or to cope with environmental threats in competitive settings (Coccia, 2019a, b, 2020c). In general, underlying motivations of nations to produce science advances and new technology in society, in the presence of environmental threats (e.g., COVID-19), can be: achieve and/or sustain endogenous power and leadership in international system, higher reputation in the international system with challenges in big science and path-breaking technologies, support of economic growth and wellbeing of citizens (Coccia, 2019a, b, c).

Finally, a comparative analysis of crisis-driven research field and problem-driven research fields shows some main characteristics of the research behavior in a period of crisis (Table 10).

Results show that research behavior in crisis is mainly open access for a widespread diffusion of scientific results for a higher impact in scientific communities and society; in fact, products in COVID-19 research have about 76% of open access, whereas in COPD is 40% and Lung cancer is 36%. In addition, scientific production of research field driven by a crisis (COVID-19) has a higher publication density based on short communication given by letters (about 12%) *versus* 2–3% in COPD and Lung Cancer studies; notes have higher frequency of about 6% in COVID-19 research, whereas is about 2% for COPD and Lung cancer studies. Overall, then, the research behavior in a crisis-driven research field is directed to short contributions for providing concise, clear and new results for a rapid and vast diffusion in science and society.

Discussion

The study here, based on empirical analyses of COVID-19 research, has theoretical implications to explain the dynamics of science and research behavior in periods of crisis that generate scientific discoveries and technological advances.

This study suggests that (Table 11):

- *Problem-driven* research fields are guided by problems in nature and/or society (e.g., lung cancer, Alzheimer disease, environmental pollution, etc.) and the evolution is mainly due to endogenous processes in science (e.g., social interaction between groups of scholars and scientific communities) that generate discoveries and science advances in the medium-long run (Sun et al., 2013).
- *Crisis-driven* research fields are due to exogenous factors, which generate environmental threats in society, which stimulate scientific research to find solutions in a limited amount of time before can permanently damage socioeconomic systems (e.g., pandemic, war, etc.). The evolution of crisis-driven research fields has, in the starting phase, an exponential growth that fosters science advances and scientific discoveries in the short run.

In particular, some unique characteristics of the evolution of crisis-driven research fields can be systematized with following empirical properties of the dynamics of science under crisis:

1. *Drivers of environmental threat.* Evolution of crisis-driven research field is due to a new and consequential environmental threat in human society to be solved in the short run, such as COVID-19 global pandemic crisis, supporting a high average rate of growth of scientific production.

   Remark: Evolution of research field not driven by crisis, called here problem - driven, has an average rate of growth of scientific production equal to about 0.4% daily.
2. *Concentration of scientific production.* Evolution of crisis-driven research fields is pulled by few (parent) disciplines (3–5) that generate more than 80% of documents. In the case study of COVID-19, critical disciplines are given by medicine, biochemistry, genetics and molecular biology. This crisis-driven research field of COVID-19 confirms the property of science dynamics by Coccia (2018a, b).

Table 11 Characteristics of the evolution of problem-driven and crisis-driven research fields in science

Origin	Problem-driven research fields	Crisis- driven research fields
Type of evolution	Linear in short and long run	Exponential in the short run, linear in the long run
Growth of scientific products in the initial phase of development	Arithmetic increment	Geometric/Exponential increment
Active institutions	Public research organizations and public/private universities	Public research organizations and public/private universities
Funding institutions	Public funding institutions and foundations	Public funding institutions and foundations
Prolific countries	Rich countries	Rich countries
Open Access	Low intensity	High intensity
Document type	Articles and conferences	Articles, letters and notes
Discoveries and paradigm shifts	Long-run	Short-run
Example of research fields	COPD, Lung Cancer	COVID-19

3. *High production of public and private research organizations.* The most active institutions in crisis-driven research are mainly public research labs and public/private universities localized in advanced countries.
4. *Public funding*. Main funding institutions in scientific production of crisis-driven research field are public organizations of rich nations and global charitable foundations.

   Remark: Data show that in June 2020, in the initial phase of COVID-19 pandemic, premier biopharmaceutical companies (e.g., AstraZeneca, Merck, Novartis, Pfizer, Roche, etc.) timely funded scientific research for this global health issue and some of them have generated scientific and technological breakthroughs given by novel vaccines and new oral antiviral COVID-19 drugs to treat this new infectious disease (cf., Coccia, 2017c).
5. *Global leadership*. Scientific production of crisis-driven research fields is due to rich countries that generate about 78% of documents direct to support their global leadership (cf., Coccia, 2015a, 2017a, b).

   Remark: This result is due to high levels of R&D investments in rich countries that support scientific and technological advances (Coccia, 2009, 2012, 2018a; Kealey, 1996; Price de Solla, 1986). These results can be due to critical socioeconomic factors of leading countries in supporting the research in a period of crisis, such as the research field of COVID-19, as explained by Coccia (2019a, b, 2019c):

   - Science advances and new technology are a source of socioeconomic power for countries to take advantage of important opportunities or to cope with consequential environmental threats in society.
   - Science advances and new technology are drivers of economic and productivity growth for nations and of a higher wellbeing of citizens.
   - Science advances and new technology increase reputation and recognition of nations worldwide to support an endogenous power in international system based on a scientific and technological superiority that endorses their leadership and affects other geo-economic regions to take advantage of commercial and political opportunities (cf., Coccia, 2015a, 2015b).

6. *Open source production*. Research behavior of crisis-driven research field is mainly based on scientific publications having open access for a vast diffusion of results to increase impact in science and society.
7. *Short communication*. Scientific production of crisis-driven research field has a higher density of short communications with letters and notes to systematize quickly findings to publish and spread worldwide.

In general research fields evolve with accumulation of "normal science" (e.g., COPD and lung cancer) that generates discontinuous transformations in the long run that support the transition from an existing scientific paradigm to an emerging one (Kuhn, 1996). However, what this study adds is that in the presence of environmental threats in human society (such as, COVID-19 global pandemic crisis), the evolution of research has accelerated rates of growth that generate discoveries and science advances in the short run to solve new problems and/or reduce their negative impact in society. In fact, crisis-driven research field of COVID-19 has accelerated the transition towards innovative types of drugs, e.g. mRNA vaccines, generating a paradigm shift to treat infectious diseases (Abbasi, 2020; Coccia, 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g; Heaton, 2020; Jeyanathan et al., 2020). Finally, research behavior in the presence of

crisis management is also based on systematic and improvised activities directed to the use of inventive analogies (e.g., innovative drug of other diseases applied for COVID-19, see the monoclonal antibody Tocilizumab) for supporting solutions of complex problems in a limited amount of time (Ardito et al., 2021; Bonnardel, 2000).

Conclusions and limitations

Social studies of science show that factors determining the evolution of research fields are due to endogenous factors in science, such as the interaction between scientific communities (Leydesdorff, 2015; Sun et al., 2013). However, this study reveals that the evolution of research fields can be also due to crisis, such as the research field of COVID-19 originated in 2019. In particular, environmental threats and unpredictable crisis can support the origin and accelerated evolution of research directed to explain and solve unknown problems, by generating discoveries, and also scientific and technological paradigm shifts (cf., Becsei-Kilborn, 2010).

These conclusions are of course tentative. A limitation of this study is that sources under study may only capture certain aspects of the on-going dynamics of science in a period of crisis. In addition, high production rate and high publication frequency in the research field of COVID-19 can be also due to the fact that in the presence of emergency and crisis, studies associated with COVID-19 have been published without formal procedures of publication. This technical issue may have increased publication frequency, and as a consequence control factors need to be considered in future development of this study. Overall, then, there is need for much more detailed research with additional data to clarify the relations and scientific change underlying the evolution of research in the presence of crises and environmental threats, such as to consider also collaboration intensity, openness of products, intellectual property rights, different sources/procedures of academic publications, different motivations associated with research funding, etc. To conclude, this study is a preliminary analysis that is going to be developed over time.

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