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Synthetic biology and governance research in China: a 40-year evolution

Li Tang[1] · Jennifer Kuzma[2] · Xi Zhang[3] · Xinyu Song[4] · Yin Li[1] · Hongxu Liu[5] · Guangyuan Hu[6]

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Abstract
The governance of emerging technologies has become a topic of global concern, not only for national competitiveness, but also for national security. Among other technologies, synthetic biology (SynBio) has been prioritized in the policy agenda of many countries; China is no exception. Unfortunately, despite the interconnectedness of governance practices and research development, few studies have investigated the current situation and development trajectory of this emerging dual use technology. To fill in this gap, this study focuses on China and investigates the pattern and evolution of its SynBio and related biosafety and biosecurity research published in both domestic and international databases. We find that despite its late entrance to the field, national government funding plays a critical role in China's SynBio research. However, the funding ratio of SynBio as well as SynBio safety research is lower than China's average when considering all fields. The structural topic model analysis reveals that the biological sciences dominate China's SynBio research and slowly diffuse to other disciplines such as materials science, physics, and medicine, while perspectives from Chinese social scientists are barely recorded on the international academic stage. We also find little overlap of topics between China's domestic and international output on SynBio and its safety research. Speculations and policy implications are discussed in the end.

Keywords Synthetic biology · Biosafety · Biosecurity · Structural topic model · Governance of emerging technologies

Introduction

The governance of emerging technologies has become a topic of great concern globally in a time of pandemic and war (Tang & Cao, 2022). This is not only an issue of international technological competitiveness but is also a matter of maintaining national security. In addition to their far-reaching impact on many aspects of human life, another common challenge of emerging technologies (such as nanotechnology, artificial intelligence, and synthetic biology) is their uncertain and unpredictable development trajectories (Greely, 2022; Khalil & Collins, 2010; Shapira et al., 2022; Trump et al., 2020a, 2020b; Voigt, 2020).

Extended author information available on the last page of the article

Synthetic biology, or *SynBio* has been called the "third biological revolution," after the discovery of the DNA double helix structure and sequencing of the human genome. Spanning the fields of biology, engineering, physics, chemistry, and information and computer science(Cheng & Lu, 2012; Gomez-Tatay & Hernandez-Andreu, 2019; Hu & Rousseau, 2015; Kuzma, 2022), this dual-use and disruptive emerging technology aims at engineering new biological systems that do not exist in nature.[1] Its profound impacts extend beyond public health, environmental protection, and economic development to national security and global competitiveness (Brooks & Alper, 2021; Tang et al., 2021). Since the twenty-first century, major developed countries have raced to invest in the field and prioritize SynBio at the top list of their national research agendas. Over the period of 2004–2013, European countries invested about 450 million euros in SynBio research (Bueso & Tangney, 2017; Commission, 2014). Particular attention is being paid to the safety and security of this novel field.

For instance, in June 2018, the US National Academy of Sciences released the roadmap report "Biodefense in the Age of Synthetic Biology," which addressed biosafety and biosecurity issues and proposed a defense framework. The Department of Defense was urged to strengthen public health infrastructure to guard against potential biological attacks. In the UK, the national Innovation and Knowledge Centre for Synbio (SynbiCITE, 2020), applied the notion of responsible innovation proposed by the UK Engineering and Physical Sciences Research Council (EPSRC) to the field of synthetic biology, and proposed a series of governance methods. From SYNBIOSAFE, the first European project particularly targeting on the safety and ethical concerns of SynBio research (2007–2008), to the SYNENERGENE Project (2013–2016), and to the SMART-Map Project (2016–2017), European countries have been also actively promoting this field, ranging from formulating global framework agreements, facilitating global engagement on ethical discussion, and other steps.

China has also placed great importance on the development of synthetic biology. From the 12th 5 year Biotechnology Development Plan, the 12th 5 year Special Plan for National Basic Research and Development, to the 13th 5 year National Science and Technology Innovation Plan, China's research and development (R&D) funding for this key area has escalated rapidly. At the end of 2019, the National Synthetic Biotechnology Innovation Center was launched, a milestone in China's institutionalization of synthetic biology research. As illustrated in Fig. 1, in 2016 China surpassed the UK and since then become the second-largest knowledge contributor in SynBio.

Meanwhile, along with the deepening of international discussions on the potential safety hazards and research ethics of dual-use disruptive technologies, the governance of SynBio safety and security[2] have also attracted the attention of the Chinese government and academia. For example, some scholars insist that SynBio R&D must adhere to responsible innovation and follow dual-use technology ethics principles. Some propose *The Code of Conduct for Biological Scientists* for SynBio governance. Some also advocate that SynBio researchers

[1] The workable definition of dual-use was discussed in Forge (2010). It is widely accepted as research that is intended for benefit but which might be misapplied to do harm (Kuzma et al., 2017).

[2] Safety and security in this context often refer to the unique concerns incurred by synthetic biology. For example, Ahteensuu (2017) noted that SynBio safety mainly concerns "research personnel working with synthetic organisms and potential damage to the environment and population surrounding the research area," while SynBio security is often related to the potential misuses of this technology, such as bioterrorism, biowarfare, or bioattacks (Gomez-Tatay and Hernandez-Andreu, 2019). In this paper, for the sake of brevity, we use the term *SynBio safety* to refer to both safety and security in the field.

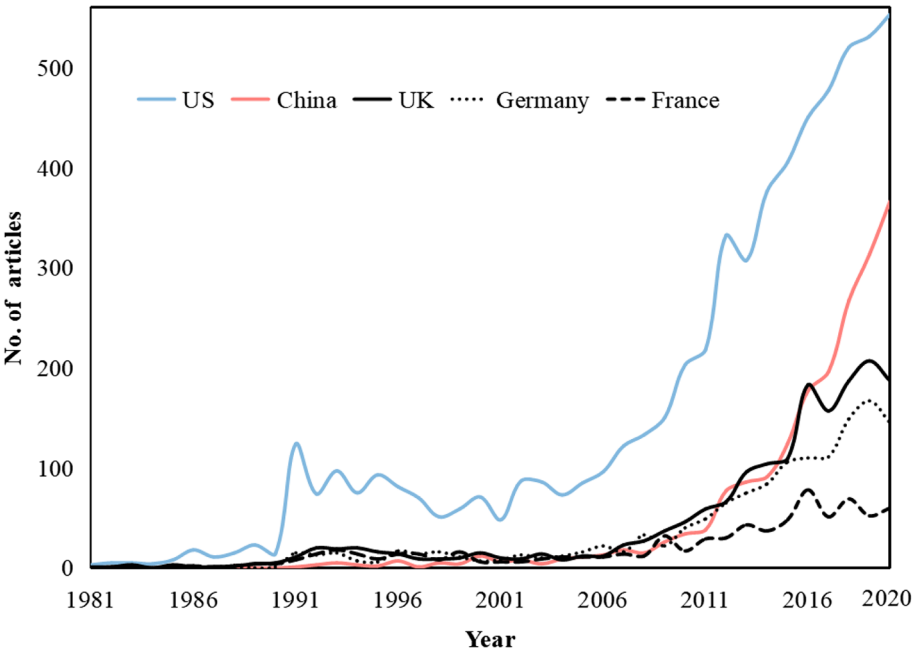


Fig. 1 SynBio publication trends for the top five countries. UK publications consist of those contributed by England, Scotland, Wales, and Northern Ireland. China's publications consist of those contributed by mainland China, Hong Kong, Macau, and Taiwan

enhance international vision and global cooperation, develop a platform for joint consultation and governance, and stay alert to the risks to natural ecosystems, social ethics, and moral challenges. In 2018, the Ministry of Science and Technology of China designated funding for several key projects on ethics and safety concerns related to SynBio. In October 2020, the Standing Committee of China's 13th National People's Congress passed *The Biosafety Law.* This comprehensive framework legislation established a legal guard against biosafety risks to promote the healthy development of biotechnology.

Despite this endeavor, compared to other countries' SynBio research and biosafety governance practices, China still lags far behind meeting its national strategic needs. There has been very little reporting on the development of China's SynBio research, and even less discussion on incorporating biosafety and biosecurity assessments into public decision making. To fill these gaps in the existing literature, this study constructed a unique dataset of China's SynBio and SynBio safety research published in both domestic and international journals. Combining traditional bibliometrics and structural topic modeling, we examine development patterns through four dimensions: quantity, leading institutions, funding, and research themes evolution. The findings are expected to shed some light on China's future emerging technology governance policymaking.

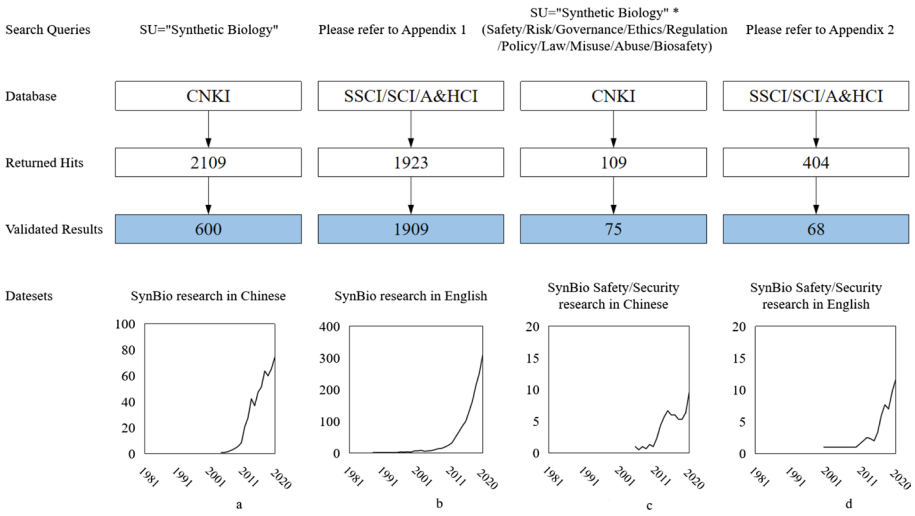


Fig. 2 Publication trends of China's SynBio and SynBio safety research. Panels **a–d** depict Chinese SynBio and SynBio safety research indexed in CNKI and WoS databases, respectively. Only the document types "articles" and "reviews" are included for analysis. To reduce the fluctuation of annual publications, a 3 year moving average is presented

Data

The two main data sources used in this study are China National Knowledge Infrastructure (CNKI) and the Web of Science database (WoS). One challenge of evaluating the research capacity of non-English-speaking emerging countries is that global publication databases, such as WoS, cannot capture research achievement written in their domestic languages. A strength of this paper is that we combine research output indexed in both domestic and international scholarly databases to understand the features and research themes of China's SynBio and SynBio safety research.[3]

The data acquisition took the following steps:

China's domestic publications in synthetic biology. Using "synthetic biology" (pinyin: *hecheng shengwuxue)* as the search term, we downloaded all publications from the three major data sets of CNKI, namely the journals, master's and doctoral dissertations, and conference proceedings data sets. This returned 2109 papers. After excluding retractions, editor's notes, editorials, and news, 1458 SynBio research papers were retrieved to form our Chinese language research pool. Considering publication quality and possible overlap between journal publication datasets and the other two CNKI datasets, we next focused on SynBio journal articles. After independent abstract screening by two authors, 600 peer-reviewed research papers were selected (Fig. 2a).

[3] CNKI publications were downloaded in May 2020 and updated in October 2022. The WoS publications were downloaded in June 2022. The publication coverage of our sample in both databases is from 1981 to 2020.

China's international publications in synthetic biology. Building upon and refining the search queries of existing research (Oldham et al., 2012; Raimbault et al., 2016; Shapira et al., 2017), after consulting three SynBio research scientists, we retrieved 1923 articles with Chinese affiliation in the three databases of WoS core datasets, namely Science Citation Index Expanded (SCIE), Social Science Citation Index (SSCI), and the Arts and Humanities Citation Index (A&HCI).[4]We finalized 1909 articles after removing irrelevant and duplicate publications. A further examination revealed all these articles were written in English. We thus use the terms *China's international publications* and *China's publications in English* interchangeably in following sections (Fig. 2b).

China's domestic publications in SynBio safety. Using a composite Boolean search on biosafety and biosecurity in CNKI journal dataset, 109 publications were identified as SynBio safety research. Following full text reading and verification, 75 SynBio safety papers were finalized for further analysis (Fig. 2c).

China's international publications in SynBio safety. In the same vein, we searched and retrieved 404 articles on SynBio safety and security based on existing studies (Gomez-Tatay & Hernandez-Andreu, 2019; Perkins et al., 2019; Trump et al., 2019). Two researchers independently examined the full texts and finalized 68 articles (Fig. 2d).

Bibliometric analysis

Overall trends

As shown in Fig. 2, China's research in SynBio and SynBio safety experienced two stages of growth, with 2010 as a watershed year. One speculation is that the outbreak of severe acute respiratory syndrome (SARS) in 2003 catalyzed the progress of Chinese biomedical science, and particularly coronavirus research. With the advent of the first man-made cell *Cynthia* in 2010, the ethical and safety challenges associated with synthetic biology captured particular attention in Chinese academia. China's R&D investment and SynBio safety research has since increased dramatically. And the debate on whether or not and to what extent that SynBio should adopt the principles of prudent and vigilant development continues today. It is anticipated that the ongoing COVID-19 pandemic will propel SynBio and SynBio safety research to a new peak.

Institutional analysis

At the institutional level, as illustrated in Fig. 3, a growing number of Chinese universities and research institutions have begun investigating SynBio. This is not only true for domestic publications, but also for international publications. The amount of SynBio research written in Chinese by first authors with Chinese institutional affiliations rose from 24 in 2011 to 44 in 2020, nearly doubling over a 10 year period. For international journal articles, the amount of SynBio research written by first authors with Chinese institutional

[4] For example, after consulting synthetic biologists and scholars who have conducted research on safety and security issues of synthetic biology, we added "engineering biology*" into the search terms. For detailed search queries of synthetic biology and SynBio safety research, please refer to the Appendices section.

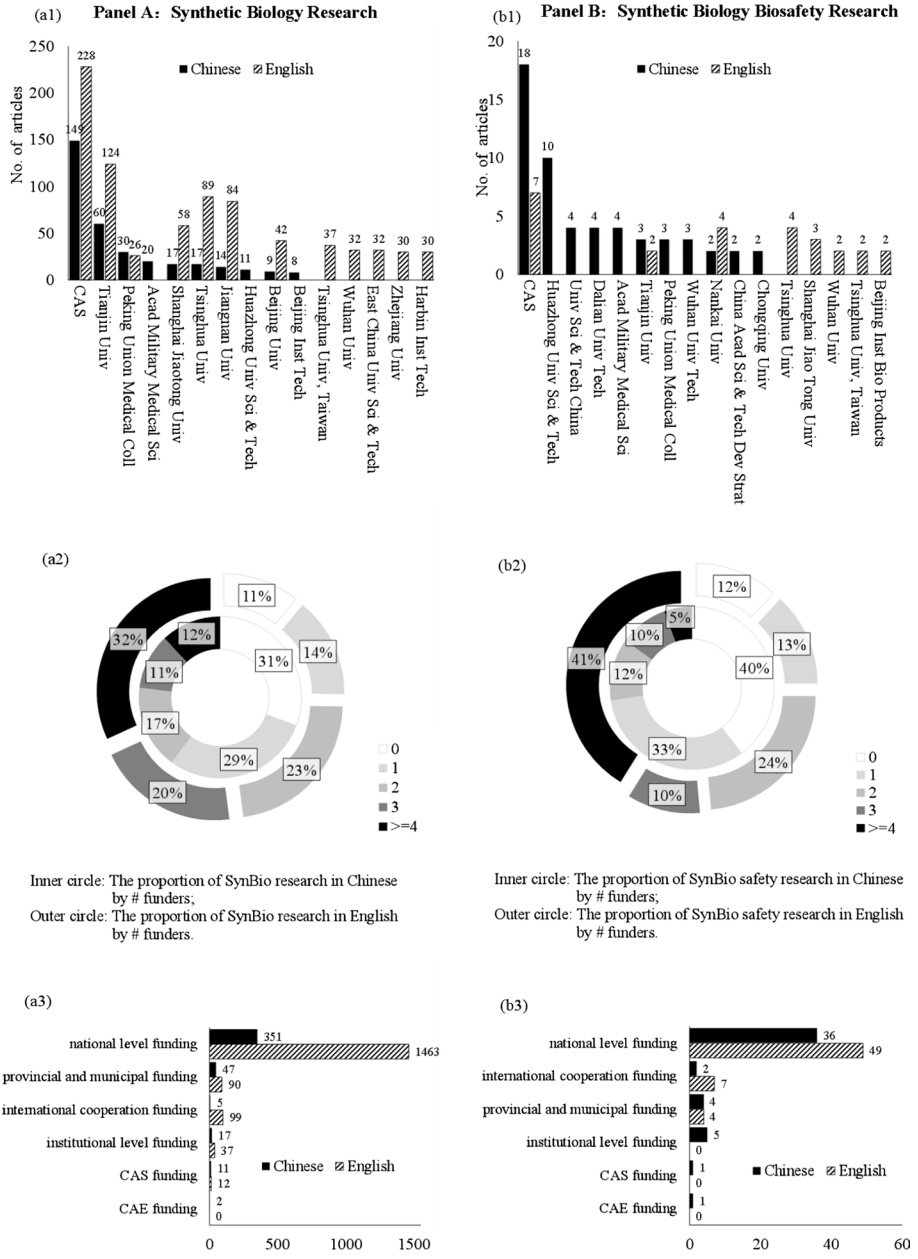


Fig. 3 Patterns of China's SynBio and SynBio safety research: 1981–2020. Panels a and Panels b are snapshots of China's SynBio and SynBio safety research respectively. **a1** and **b1** list the names of the first authored organizations with most SynBio and SynBio safety publications differentiated by written languages. **a2** and **b2** depict the number and proportion of funded research in our analyzing sample. **a3** and **b3** demonstrate different types of funding reported in SynBio research. For articles with multiple funding, the highest level of funding is reported

affiliations jumped from 27 to 97 over the same period. Some institutions have emerged as vanguards in this research landscape. In our analyzing sample, nearly 60% Chinese articles on SynBio are first-authored by researchers affiliated with the top 10 institutions (Fig. 3a1). Among them, the Chinese Academy of Sciences (24%), Tianjin University (11%), Peking Union Medical College (5%), the Academy of Military Medical Sciences (4%), and Shanghai Jiao Tong University (3%) are the top five, in descending order, over the examined 40 year period.

In the area of SynBio safety, despite China's late entrance, several Chinese universities and research institutes have demonstrated their research excellence. As shown in Fig. 3b1, the top five scientific research institutes (the Chinese Academy of Sciences [26%], Huazhong University of Science and Technology [14%], University of Science and Technology of China [6%], Dalian University of Technology [6%], and the Academy of Military Medical Sciences [6%]) in total contributed 57% of SynBio safety research in China from 2011 to 2020.

Funding pattern

As a widely used policy tool to direct or redirect scientists' attention and research portfolios (Shapira & Wang, 2010; Tang, 2022b), government funding also serves an important driving force for the R&D and governance of emerging dual-use technologies. Our data shows that 71% of China's SynBio research and 63% of SynBio safety research claim financial support in their acknowledgements, putting the caveats of funding acknowledgment analysis aside (Liu et al., 2020; Paul-Hus et al., 2016). These statistics are lower than the average funding ratio other Chinese basic science (Tang, 2022a). A closer examination reveals that China's national government research fund is the main source of investment for both SynBio and SynBio safety, accounting for 58% and 47% respectively (Fig. 3a3, b3). Another finding worthy of note relates to braided or hybrid funding: approximately 40% of China's SynBio research was funded by at least two or more sources, of which about 7.6% report four or more sources. Similarly, in the field of SynBio safety, nearly one-third were funded by two or more sources. Overall, the funding ratio of SynBio safety research is 8 percentage points lower than that of SynBio itself, and the proportion of national funding is 11 percentage points lower than that of synthetic biology. This suggests, assuming that the patterns of funding acknowledgment reporting do not differ significantly for the two types of research, SynBio safety and security research has not attracted the same attention as SynBio itself.

STM analysis

Theme evolution of publications can be helpful in spotting potential technology adoption (Grey et al., 2022) and signaling where the path of governance practice should take on. Researchers have adopted keyword co-occurrence, social network analysis, latent dirichlet allocation, or LDA (Blei et al., 2003), to name just a few, to portrait the evolution of research streams. In this paper, given the multidisciplinary feature of SynBio and its safety research (Blaydes et al., 2018), we adopt a recently developed structural topic model (hereinafter *STM*), an unsupervised machine-learning technique, to analyze theme dynamics (Grajzl & Murrell, 2019; Roberts et al., 2014, 2016). After the optimal number of topics is determined, STM allows us to exploit research themes without preconceived notions

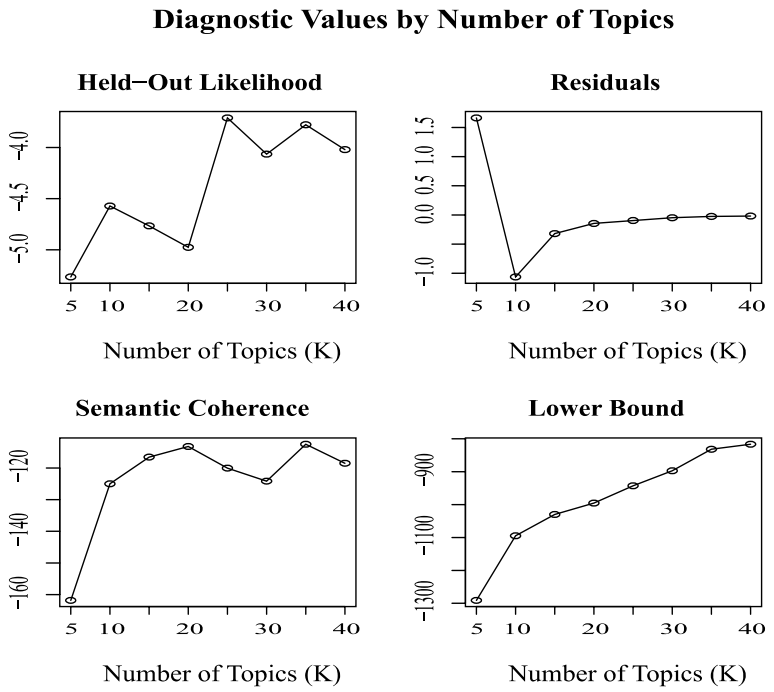


Fig. 4 Goodness of fit by number of topics in China's domestic SynBio publications: 1981–2010

(Grajzl & Murrell, 2019; Roberts et al., 2016). Following previous studies (Grajzl & Murrell, 2019), we identify the themes based on the cooccurrence of words across Chinese SynBio and SynBio safety research within a specific time period.

Thematic evolution of China's SynBio research

The R software package (version 4.03) was used to analyze the abstracts of articles. Following preprocessing textual data and removing words without clear semantics, such as punctuation, numbers, stop words ("of", "is", "then" and so on), the resulting data set consists of 600 Chinese documents and 34,504 word tokens. We conducted a series of STM models with a varying number of topics ranging from five to 40. Using every five topics as an increment, we tested the validity of the topic model of varying number of topics. Figure 4 demonstrates China's domestic SynBio research prior to 2010.

As illustrated in the held-out likelihood, the size of residuals, the average semantic coherence, and the lower bound (Fig. 4) we next assessed goodness of fit with these different number of topics (Grajzl & Murrell, 2019). As suggested by extant research, the fitting results should have relatively low residuals and bounds and higher held-out likelihoods and semantic consistency. For a detailed description of STM operation process please refer to Albert (2020), Curry and Fix (2019), and Sharma et al. (2021). We chose 10 as the topic number for China's domestic synthetic biology research prior to 2010.

We next ranked these top 10 topics according to their relative importance in the corpus (Schwemmer, 2018). The expected topic ranking reflects the weight of each topic in all

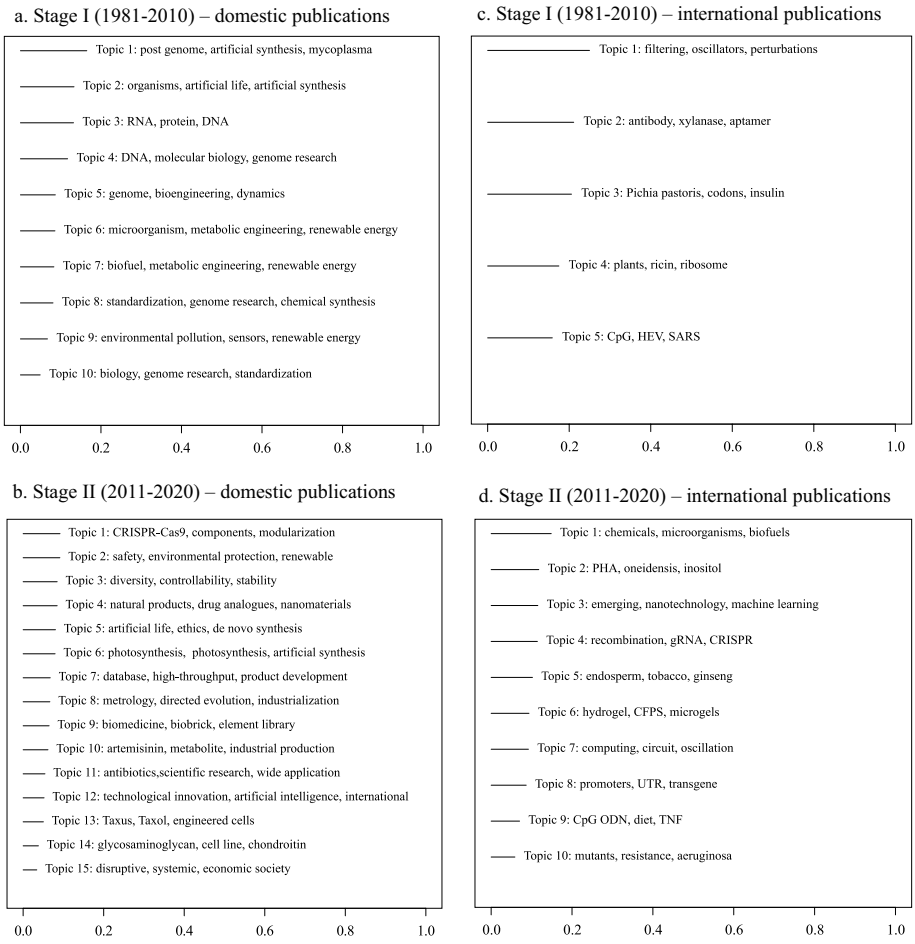


Fig. 5 Expected proportional values for topics in Chinese SynBio research. **a** presents the top 10 topics of China's SynBio research identified by the STM model during the period of 1981 and 2010. **b** presents the top 15 topics of China's SynBio research over the second phase between 2011 and 2020. **c** and **d** list the top 15 topics of China's SynBio research published in international publication databases during the two phases, respectively. In each panel, the *x*-axis represents the proportions of expected topics and the *y*-axis denotes the expected topics in descending order and their most common words. For each topic, the top three FREX words are displayed. The size of the bars to the left of each topic is proportional to the probability that a random word drawn from the whole corpus generates that particular topic

texts; the higher the ranking, the higher the probability that the topic is discussed. The top three most common words that define that topic in the model and the proportion of the topic are demonstrated in Fig. 5a. The frequency-exclusivity (FREX) lexical method was adopted in recognizing topic names and distinguishing common words in different topics (Bai et al., 2021; Grajzl & Murrell, 2019). Topic 1 (namely "post genome, artificial synthesis, mycoplasma") is of the most importance, with the expected topic ratio exceeding 0.2. The remaining nine topics with the expected topic ratios are in the range of [0.05, 0.15].

The same procedure was adopted for China's SynBio research from 2011 to 2020. We again tried a varying number of topics, from five to 40, and conducted a series of goodness-of-fit analyses. A selection of 15 topics and their three commonly used FREX words

are presented in Fig. 5b.[5] If we compare the topics and FREX vocabulary of Fig. 5a and b, we can see China's SynBio research expanded from genome and artificial life bioengineering in phase I to more diverse fields such as CRISPR-Cas9, environmental protection, industrial production, and so on in the second stage. In the same vein, we plot the research theme evolution of China's international publications in SynBio (Fig. 5c and d). As shown, topics related to pharmacology and toxicology (such as apoptosis, hTERT, and cancer) and plant and animal science (such as endosperm, melatonin, and unigenes) also appear on the list of top research themes.

SynBio is an interdisciplinary field where explorations are conducted from different research domains. Figure 6 visualizes the disciplinary expansion of China's SynBio research. As shown by its domestic publication dataset, Chinese SynBio mainly focused on the field of biological sciences. Starting in 2011, scientists in industrial technology, medicine, and health have demonstrated their interest in this topic. Investigations from philosophers and religious scholars remains sparse. These findings are similar in international publications. Biology and biochemistry research dominates the scholarly discussion. Scientists in materials science, physics, and medicine have begun gradually incorporating SynBio research, while perspectives from Chinese ethicists and philosophers are almost completely out of the picture.

Thematic evolution of Chinese SynBio safety research

We adopted the same method to test the goodness of fit of different topic models of SynBio safety research published in both Chinese and international databases. We select six topics for China's domestic SynBio safety research and three topics for its international SynBio safety research to demonstrate the highest topic ratios.[6] The results are shown in Fig. 7.

Two findings revealed by Fig. 7 are worthy of note. To begin with, China's domestic and international research demonstrate different concerns related to SynBio safety. We found little overlap of the top topics between China's domestic and international research on SynBio safety. The former encompasses broad aspects involving uncertainty, ethics, and regulations from interdisciplinary researchers, while the latter focuses primarily on specific concerns on therapies, tumors, biofuels, crops, cadmium (II) ions, and so on.[7]Secondly, opinions from social scientists are boxed out in Chinese

[5] For the sake of brevity, we do not report the diagnostic process of selecting the number of topics for China's domestic publications in the second phase of 2011–2020 and for the research published in international journals. This process is available upon the request; please contact the first author or corresponding author.

[6] The selection process of topic numbers for Chinese SynBio safety publications in domestic and international databases are available upon request to the first author or corresponding author.

[7] We speculate there are two reasons for why topics published within China differ from those published in international journals. One explanation could be that Chinese SynBio scientists who published in domestic and international journals are different sets of scholars. To test this hypothesis, we retrieved the names and spellings of all first authors in our dataset. We found the overlapping authors between Chinese domestic publications and international publications were only 4.51% for SynBio and 0.84% for SynBio safety over the examined 40 years. The second explanation relates to journal self-selection. Using SynBio safety research as an example, it is reasonable to believe that journals' different preferences contribute to the disparate topics shown in Figs. 5 and 7. To examine this argument, we first selected the top five CNKI- and WoS-indexed journals by the number of Synbio safety publications from our analyzing dataset. We next retrieved and identified, collectively, their top keywords (authors) in the entire dataset over the examined period between 1980 and 2020. As presented in Appendix 3, the two groups of journals demonstrate distinct pattern of themes.

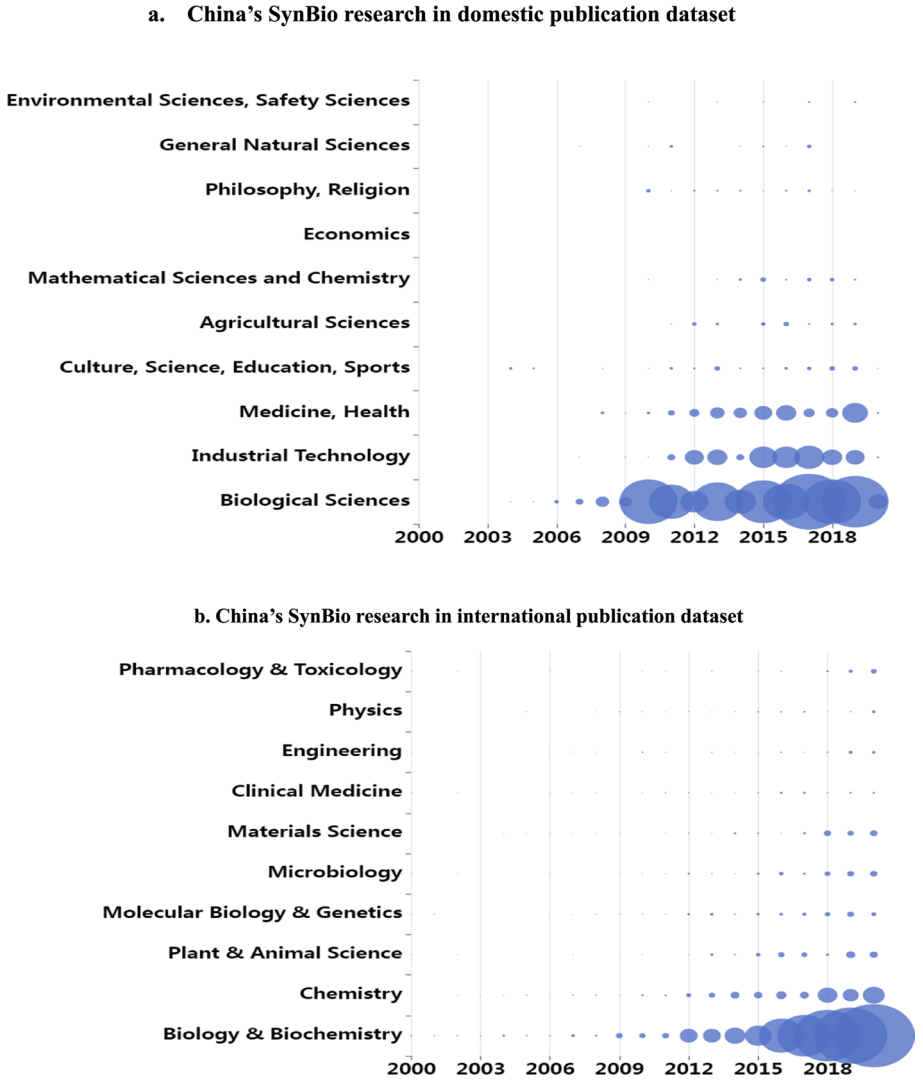
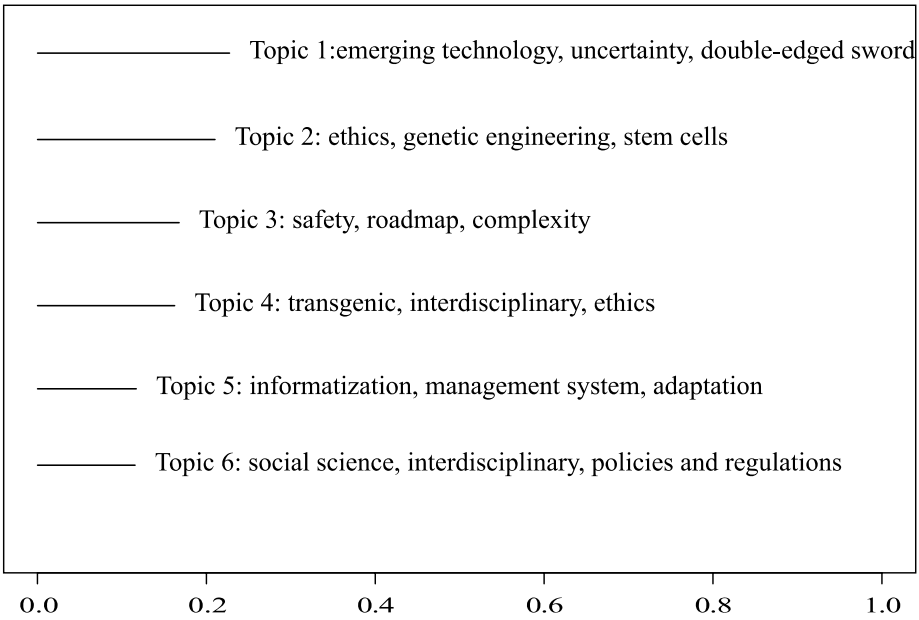


Fig. 6 The evolution of China's SynBio research by discipline. The top 10 disciplines are shown for China's domestic and international SynBio research. The names of disciplines are listed in descending order of SynBio publications in our analyzing sample. The discipline names in **a** are based on the Chinese Library Classification (fifth edition). The research discipline of China's international SynBio research is based on Essential Science Indicators. The node size is proportional to the number of publications

journals, but not in international outlets. This finding is consistent with that of Fig. 6, suggesting China's global influence in social science has lagged behind its science and technology development (Tang, 2022b).

a. China's SynBio safety research in domestic publication dataset



b. China's SynBio safety research in international publication dataset

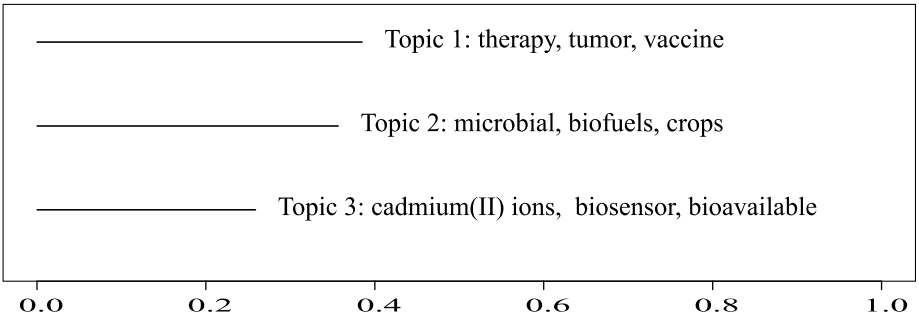


Fig. 7 Expected values for topical proportions in Chinese SynBio safety research: 1980–2020. Topics are ranked according to their relative importance in the corpus. The top three FREX vocabularies of each research topic, considering exclusivity, are reported for each topic over our examined 40-year period

Conclusion

Major findings

This article aims to understand the patterns and trends of China's research on SynBio and SynBio safety. Both domestic and international publication databases were searched over a 40 year interval between 1981 and 2020. We find, despite its late entrance to the field, China is now positioned on the first tier of global research excellence on this dual-use emerging technology. There exists little overlap of topics between China's domestic and

international output on SynBio and safety research. Some domestic Chinese universities and research institutes such as the Chinese Academy of Sciences and Tianjin University are leading development in both synthetic biology and SynBio safety research. National-level research funding plays an important role, yet the funding intensity lags behind other fields. This study also reveals that perspectives from ethics, policies, and regulations are emerging, but there is still a lack of systematic research on how to an orchestrate governance of SynBio research in and outside China.

Discussion

SynBio experts and professionals tend to agree that extant oversight and regulations do not sufficiently address potential SynBio threats and safety and security concerns (Ahteensuu, 2017; Moritz et al., 2020). It has been increasingly shown that sustainable and responsive R&D of dual-use emerging technologies requires anticipatory governance (Guston, 2014). But the governance of SynBio must adapt to the its rapid development, which should further be built upon sufficient and in-time knowledge about where SynBio is heading (Cummings & Kuzma, 2017; Guston & Sarewitz, 2002; Kuzma & Tanji, 2010; Trump et al., 2018, 2020a, 2020b; Valdez et al., 2019). Although literature on aspects of regulation, policy, ethics, social science, and governance is growing after the event of He Jiankui (Krimsky, 2019), it remains lagging in China which may require sustained policy attention to fund programs in these areas.

Our study contains some limitations. To begin with, there is no unanimously agreed definition of or queries for the emerging field of synthetic biology. As noted by the three Scientific Committees' Opinion on Synthetic Biology Biology I (2014) there have been more than 30 definitions of SynBio.[8] The retrieved literature sample, which is built upon existing research, may not allow us to identify nascent and grey studies on SynBio and their subsequent potential threat to public health and the environment. Given the rapid evolution of emerging technologies, we call for in-time monitoring on SynBio research advancement for nimble adaptation and precautionary governance. Secondly, all caveats associated with publications and bibliometrics also hold for our analysis. A considerable number of private agencies investing in SynBio are application-oriented. Moreover, only those funds reported by authors can be captured (Paul-Hus et al., 2016; Tang et al., 2017). In other words, both private investment for SynBio products and enabled applications are largely missing from our findings based on the WoS and CNKI databases. Finally, this research focuses on China, an emerging science power that has been closely tailing the US in the field since 2016. It would be interesting to examine the research lag and dynamics, if any, between China and other major economies and vanguard countries.

[8] These three committees are the Scientific Committee on Health and Environmental Risks (SCHER), the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), and the Scientific Committee on Consumer Safety (SCCS).

Appendix 1

Search queries of synthetic biology research in Web of Science

(((TS = ("synthetic biolog*" OR "engineering biolog*" OR "synthetic dna" OR "synthetic genom*" OR "synthetic *nucleotide" OR "synthetic promoter" OR "synthetic gene* cluster") NOT TS = ("photosynthe*")) OR (TS = ("synthetic mammalian gene*" AND "mammalian cell") NOT TS = "photosynthe*") OR (TS = "synthetic gene*" NOT TS = ("synthetic gener*" OR "photosynthe*")) OR (TS = ("artificial gene* network" OR ("artificial gene* circuit*" AND "biological system")) NOT TS = "gener*") OR (TS = ("artificial cell") NOT TS = ("cell* telephone" OR "cell* phone" OR "cell* culture" OR "logic cell*" OR "fuel cell*" OR "battery cell*" OR "load-cell*" OR "geo-synthetic cell*" OR "memory cell*" OR "cellular network" OR "ram cell*" OR "rom cell*" OR "maximum cell*" OR "electrochemical cell*" OR "solar cell*")) OR (TS = ("synthetic cell") NOT TS = ("cell* telephone" OR "cell* phone" OR "cell* culture" OR "logic cell*" OR "fuel cell*" OR "battery cell*" OR "load-cell*" OR "geo-synthetic cell*" OR "memory cell*" OR "cellular network" OR "ram cell*" OR "rom cell*" OR "maximum cell*" OR "electrochemical cell*" OR "solar cell*" OR "photosynthe*")) OR (TS = ("artificial nucleic acid*" OR "artificial *nucleotide")) OR (TS = ("bio brick" OR "biobrick" OR "bio-brick")))).

Appendix 2

Search queries of SynBio safety research in Web of Science

(((TS = ("synthetic biolog*" OR "engineering biolog*" OR "synthetic dna" OR "synthetic genom*" OR "synthetic *nucleotide" OR "synthetic promoter" OR "synthetic gene* cluster") NOT TS = ("photosynthe*")) OR (TS = ("synthetic mammalian gene*" AND "mammalian cell") NOT TS = "photosynthe*") OR (TS = "synthetic gene*" NOT TS = ("synthetic gener*" OR "photosynthe*")) OR (TS = ("artificial gene* network" OR ("artificial gene* circuit*" AND "biological system")) NOT TS = "gener*") OR (TS = ("artificial cell") NOT TS = ("cell* telephone" OR "cell* phone" OR "cell* culture" OR "logic cell*" OR "fuel cell*" OR "battery cell*" OR "load-cell*" OR "geo-synthetic cell*" OR "memory cell*" OR "cellular network" OR "ram cell*" OR "rom cell*" OR "maximum cell*" OR "electrochemical cell*" OR "solar cell*")) OR (TS = ("synthetic cell") NOT TS = ("cell* telephone" OR "cell* phone" OR "cell* culture" OR "logic cell*" OR "fuel cell*" OR "battery cell*" OR "load-cell*" OR "geo-synthetic cell*" OR "memory cell*" OR "cellular network" OR "ram cell*" OR "rom cell*" OR "maximum cell*" OR "electrochemical cell*" OR "solar cell*" OR "photosynthe*")) OR (TS = ("artificial nucleic acid*" OR "artificial *nucleotide")) OR (TS = ("bio brick" OR "biobrick" OR "bio-brick")))) AND ((TS = ("biosafe*" OR "biosecurit" OR "safe*" OR "securit*" OR "risk*" OR "biorisk*" OR "harm*" OR "hazard*" OR "danger*" OR "virulence" OR "toxic*" OR "terror*" OR "bioterror" OR "DURC" OR "dual use" OR "dual-use")) OR (TS = ("biocontainment" OR "containment" OR "kill switch*")) OR (TS = ("governance*" OR "government" OR "polic*" OR "law*" OR "legal*" OR "defense*" OR "biodefense" OR "prevent*" OR "precaution*" OR "responsible innovation" OR "responsible research and innovation" OR "responsible research*") OR (TS = ("regulation") NOT TS = ("cell regulat*"

OR "gene regulat*" OR "gene-regulat*" OR "regulat* of gene*" OR "regulat* of cell*" OR "regulat* of protein" OR "regulat* network*" OR "regulatory element*" OR "regulatory pathway*" OR "regulatory genetic network*" OR "nucleic acids regulatory device*" OR "complex regulatory" OR "regulatory circuit*" OR "regulatory level" OR "regulatory mechanisms" OR "chromatin regulation" OR "regulatory parts" OR "metabolic regulation" OR "regulatory system*"))) OR TS = ("ethic*")).

Appendix 3

Top research foci of SynBio journals: 1980–2020

CNKI	WoS
Escherichia coli	Mycobacterium Tuberculosis & Leprosy
DNA	Micrornas
Biotechnology	Hiv Prevalence & Prophylaxis
Genetic engineering	Lactic acid bacteria
DBA	Type strain
PCR	Biodegradation
Pichia pastoris	Gut microbiota
RNA	Influenza
Monoclonal antibody	Malaria
Prokaryotic expression	Hiv-1

The top five CNKI journals in our analyzing dataset account for more than 30% of Chinese SynBio publications. In descending order, they are Chinese Journal of Biotechnology, Biotechnology and Business, Chinese Bulletin of Life Sciences, Synthetic Biology Journal, China Biotechnology (tied for fifth), and Biotechnology Bulletin (tied for fifth). The top five WoS journals in our dataset account for 16.8% of SynBio publications written in English. In descending order, they are ACS Synthetic Biology, Metabolic Engineering, Applied Microbiology and Biotechnology, Microbial Cell Factories, and PLOS ONE

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Authors and Affiliations

Li Tang[1] · Jennifer Kuzma[2] · Xi Zhang[3] · Xinyu Song[4] · Yin Li[1] · Hongxu Liu[5] · Guangyuan Hu[6]

✉ Hongxu Liu
hxliu@tongji.edu.cn

✉ Guangyuan Hu
hu.guangyuan@shufe.edu.cn

[1] School of International Relations and Public Affairs, Fudan University, Shanghai 200433, China

[2] School of Public and International Affairs and Genetic Engineering and Society Center, North Carolina State University, Raleigh, NC, USA

[3] College of Management and Economics, Tianjin University, Tianjin 300072, China

[4] Center for Biosafety Research and Strategy, Tianjin University, Tianjin 300072, China

[5] Teaching Quality Assurance Office, Tongji University, Shanghai 200092, China

[6] School of Public Economics and Management, Shanghai University of Finance and Economics, Shanghai 200433, China