Empirical analysis of the relationship between technology innovation and basic research

Zhi-Yun Zhao and Xiao-Ping Lei*

This study analyses the relationship between technology innovation and basic research. Non-patent references analysis method is used and empirical analysis of China's biotechnology industry is done. Patent data are obtained from the United States Patent and Trademark Office website. The study shows that technology innovation in biotechnology relies more on basic research and it tends to be enhanced. The basic knowledge of technology innovation in biotechnology mainly comes from the papers of academic journals, among which America is the most important science source country to China. The study also shows that public science plays an important role in technology innovation in biotechnology.

Keywords: Basic research, biotechnology, empirical analysis, patent, technology innovation.

RELATIONSHIPS exist between basic research and technology innovation. Many studies have found that basic research is the prerequisite and catalyst of application studies, the essential drive of technology innovation[1–3]. Patents can be viewed as materialization of technologies. These legal documents are one of the few useful sources of comprehensive empirical information with a bearing on the technical properties of the invention and its relationship with features of the underpinning science[4]. As the United States Patent and Trademark Office (USPTO) or the European Patent Office (EPO) covers all countries, patents cover the majority of technological fields and industrial sectors and major patent systems, and patent data have long been used as a measure of innovative and technological development.

Basic research is the exploration to advanced science; and scientific papers and books are the main source that researchers use to make their research output public. Hence, scientific papers have become one of the important indicators to measure the level of basic research. Only by requesting patent protection can the researchers possess the exclusive right of technology innovation output. Patent does not completely represent technology innovation, but it can be the core content and foundation. Patented inventions usually involve a mix of public knowledge and private knowledge appropriated by the innovator. The front page of USPTO patent provides information about both kinds of sources. It contains a set of bibliographic information on the patent to other relevant documents – mostly earlier patents, but sometimes also scientific documents. These latter links to the scientific literature provide empirical evidence that technical invention in some way reflects – or perhaps is initiated and/or stimulated – by research activities. In cases where these citations reflect causal linkages, they can actually be seen as a paper trail of knowledge flow between science and technology. If patent is used as the indicator to measure technology innovation and scientific paper to measure basic research, to conduct bibliometric analysis on the scientific papers in patent references would reflect the reliability of technology innovation on basic research, or the contribution of basic research to technology innovation.

In the age of knowledge economy, more and more patents directly cite scientific papers to create innovation, especially in new emerging technology fields. Some scientists even apply patents for their scientific research output when they publish papers. This shows that the relationship between science and technology is growing more intimate, and that the knowledge flow between them is also becoming more direct and frequent.

Patentmetric analysis method has been used to analyse the relationship between basic research and technology innovation since 1980s. Based on citation links between patents and scientific publications, Narin and Noma[2] found an ever-closer interaction between science and technology in high-technology areas. Narin *et al.*[5] found out that 73% of scientific literature in the US patent citation comes from colleges and universities, government departments and other public research institutes, and 27% from scientists in enterprise circle; the correlation between US technology and scientific knowledge has doubled in 6 years. Meyer[6] studied whether there is direct relationship between basic research and patent technology from the perspective of non-patent references

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(NPRs)[6]. The result is that the citation of scientific literature of the patent and its frequency can reflect the mutual relationship between basic research and technology innovation, and the difference between correlative strength and interactive approaches in different fields leads to a difference in their knowledge transferring mechanisms. Tijssen[7] did a citation analysis on US patents which had quoted scientific papers from the Netherlands in order to measure the contributions of Netherland's basic scientific research to the technology innovation of the Netherlands and others countries. The results show that the number of patents which cite scientific papers from the Netherlands has significantly increased, with the domestic citation mode in the dominant position. It proves the importance of basic research in the Netherlands to its national technology innovation. Using patent citation analysis method, Hiroyuki *et al.*[8] analysed the influential patent literature of Japan and found that basic research in universities is the main theoretical source of invention patents. Guan and He[9] conducted a statistical analysis on NPRs based on patents that China applied in the US during 1995–2004. They found that the patents which cite *Science Citation Index* (*SCI*) papers in journal and technology fields present skewed distribution[9]. Lei *et al.*[10] use the couple model to measure the relationship between basic science and technology. The results show that the effect of basic research on patented invention varies according to the level of technological coupling. By analysing the front pages of patents in the field of genetic engineering, Lo[11] revealed that the basic research of universities, institutes and other public research organizations has a major influence on technology development. Wen[12] studied invention patents in the fields of chemistry, drugs and mechanical, computer and communication, and mechanical that China had applied and got the approval in 2000–2009. Using these patent data, she conducted empirical research on the relationship between national technology innovation and basic research in China.

Since China implemented the strategy of independent innovation, the investment on research and development (R&D) has substantially increased. However, the continuous increase has not brought any obvious progress in the key technology of Chinese industry. Liu and He[13] found that one of the important reasons which leads to the gap between investment increase and innovation growth is the failure to correctly understand the role of basic research in improving industrial core technology. Behind the key technology lies the long-term accumulation of basic knowledge. Due to the ignorance of Chinese enterprises to basic research over time, their innovation abilities in the industrial technology fields, which are more close to basic research (such as biomedicine) are weaker. Prior studies reveal that there is a close relationship between patent inventions and basic research in biomedicine. Narin and Noma[2] analysed NPR of US biotechnology patents published in 1978–1980, and found that biotechnology patents have quoted a large number of scientific papers and that the correlation between technology development and basic research is increasingly growing closer. Wen[12] also demonstrated that, of all the Chinese patents applied in the US, biomedicine patents have the strongest link with basic research. More than 70% of R&D activities of patent technology has directly referenced scientific knowledge from basic research, whereas only less than 25% technology innovation activities in the mechanical field does so.

Research will narrow the range of empirical analysis into a smaller yet important field: the biotechnology industry. Biotechnology is a new industry that is knowledge-based and also considered as the leading field of the 21st century. In the contemporary new technological revolution, biotechnology and information technology together are the pillars of high-technology. Currently, the development of biotechnology has apparently become the 'bottleneck' of developing countries. The United States occupies the leading position in biotechnology. It owns about half of the biotechnology companies and patents in the world and the sale of its biotechnology products accounts for more than 90% of global biotechnology product market. Audretsch and Stephan[14] showed that American biotechnology companies play an important role in transferring the knowledge of college laboratories to the market, and there is a close relationship between such companies and scientific researchers in colleges. Another study reveals that biotechnology companies in America rely on public science for very basic scientific research and there is a strong national bias in the citation patterns[15].

The biotechnology R&D ability of China is higher among Asian and developing countries; yet there still exists a large gap when compared with developed countries like America. Although studies have shown that innovation of biotechnology industry relies on basic research as for China, what kind of basic research does biotechnology innovation depend on, to what extent, from which countries does the basic research comes from, and whether it is centred on public science, etc. are not clearly known. Therefore, we studied this aspect to know the source of basic research in China's biotechnology innovation and providing correlative evidences for the government and enterprises to support basic research.

Research methodology

Non-patent references

When applying for a patent, the assignee has to prove the novelty, non-obviousness and usefulness of his invention. For this reason, his own invention is compared both by the inventor and the patent examiner with 'prior art' in

the respective technological fields. The relevant sources for judging novelty and inventive step are referenced in the patent application. These citations made by the applicant are called applicant citations. When the examiner grants a US patent, he also scrutinizes the prior art and applicant citations and may search for additional literature and list these references on the front page of the granted patent; these citations are called examiner citations. The cited material has a similarity to the ideas being claimed. The patent citation analysis in this paper is confined to examiner citations, which are listed on the front page of the patent primarily because these references are accessible in a uniform machine-readable form.

In these examiner citations, NPRs are likely to cover a diverse range of relationships between research activities and technological development and in a limited number of NPRs signify causal linkages between prior research outputs and subsequent application in patented inventions. NPRs include scientific journal papers, conference papers, tabloids, books, industrial criteria and engineering manuals and other publications. Tijssen[7] found that 81% patents which contain NPRs include the citation of their research work. The methodology applied in this work is to study the links between basic research and technology innovation on NPRs. To disclose the interconnection between basic research and technology innovation, special attention will be given to scientific papers of NPRs. Scientific papers, especially *SCI* papers, can reflect more about the conditions of basic research than other literature.

Theoretical framework

The scientific paper citations of patents show some useful information, such as authors, title, journal, volume, page and year, but it is not enough to analyse the relationship between basic research and technology innovation. Detailed information of *SCI* papers is necessary and we can get this by matching scientific references of patents to the *SCI* database.

The data in this research include patent data and scientific paper data. Patent data come from the USPTO patent database. The US patent data are chosen for several reasons. First, the US patent is the symbol of new technology in the world. About half of the inventors of US patents are foreigners. The proportion of US patents of other countries and districts to the total number of US patents has a generally positive relationship with that of GDP. Second, the US patent data library features large data quantity, high quality, wide coverage and convenient search, which is usually considered as the preferred patent data library of such researches. Third, the US is the global leader in the field of biotechnology. Therefore, it is more convincing to analyse China's technology innovation situation in biotechnology with the USPTO patent data. As for scientific paper data, the *SCI* data library provided by ISI Web of Knowledge platform of Thomson group is chosen. The library is also frequently used by these researchers, featuring the comprehensiveness, completeness and definitiveness.

The matching process of scientific references of patents and *SCI* papers conforms to the following steps (see Figure 1): First, the patent number and NPRs are extracted to establish the NPR database. Secondly, after the simple removal of repeated non-patent literature, it is time to match the titles, authors, years and other relevant information extracted from NPRs with *SCI* database and then to collect *SCI* paper information and set up local NPR database. Finally, *SCI* paper data collected include a unique identifier of the paper, *Web of Science* (*WoS*) accession number. In the NPR database repeated data exist. With the second removal of repeated papers based on *WoS* accession number, we can get the final NPR database without any repetition.

NPR analysis methodology

To analyse the relationship between technology innovation and basic research by patent NPRs, the method of study mainly includes the following aspects:

Science linkage analysis: Science linkage, being an important indicator of patent citation analysis, is the average number of scientific research papers or reports cited in patents. It can reflect to what extent technology innovation depends on basic scientific research. The science linkage of different periods in the same technology field would reflect the trend over time of how technology innovation in this field relies on basic research.

Journal source analysis: The more kinds of journals involved in scientific papers the patent cited, the more basic research production of different journals are cited and patent technology would rely more on basic research knowledge. The analysis of source journals of patent-cited scientific papers in different technology fields helps not only to measure the reliability of technology innovation on basic research, but also determine the core journals of patent citation in various technology fields, providing guidelines for technology researchers to absorb and utilize external knowledge in the process of technology innovation.

Nationality analysis of papers: By the analysis on the authors' countries of *SCI* citation, the geographical sources of science knowledge cited in the innovation process of the patent technology can be learned. The more the number of papers cited by patents from own country, the more technology innovation depends on that country's basic research. If, however, technology innovation mostly depends on the basic research results of foreign countries, the ability of independent innovation becomes weaker.

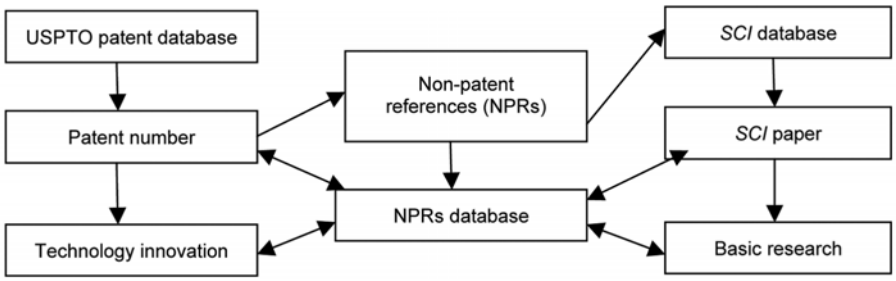

Figure 1. Theoretical framework of the relationship between technology innovation and basic research.

Public science analysis: Public science is defined as scientific research performed in and supported by governmental, academic and charitable research institutes[3]. Nelson[16] and Arrow[17] showed that the output of basic research possesses the nature of public goods, thus it results in market failure. Therefore, basic research needs to be supported by government. Research on the contribution of public science to technology innovation can offer useful evidences for the government to support basic research.

Knowledge transfer speed analysis: Knowledge transfer speed is defined as the time delay between the published year of cited papers and the year of issue of the patent. It can also be regarded as the time of knowledge transfer from basic research to technology innovation. We do not use the patent application year to calculate the delay time because some papers are cited after the patent application is published, and this will lead to the negative calculative number of knowledge transfer speed. The time delay of patents citing *SCI* papers reflects the age of the patented technology used in the course of its R&D of basic research knowledge. The short time delay indicates that the scientific basis of R&D activity and technology innovation is mainly from new scientific knowledge.

Results and analysis

Data collection

To acquire biotechnology patent from the USPTO website, a patent search query of biotechnology needs to be constructed. The study adopts technology classification system of the National Bureau of Economic Research (NBER) which is built for the USPTO on the basis of the U.S. Patent Classification System (USPC). In the system, 'biotechnology' categories corresponding USPC patent classification are '435' and '800'. With these two USPC classifications and assignee's country of 'CN', 214 issued biotechnology patents of China got searched in February 2012. These biotechnology patents cite 2883 non-patent literature. The distribution of patent citations of non-patent literature is shown in Figure 2.

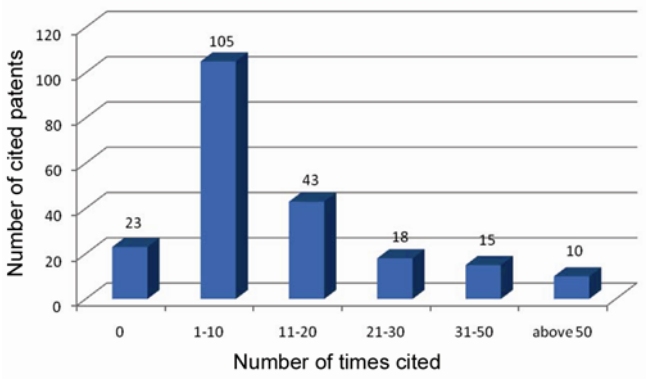

Figure 2. Distribution of patent citations from the biotechnology patent set.

Figure 2 shows that 23 patents did not cite any non-patent literature. The patents which cited 1–10 non-patent literature account for the largest proportion, that is, 105 patents, about half of the total number. There are 43 patents that cited 10–20 non-patent literature; 18 cited 21–30 non-patent literature; 15 cited 31–50 non-patent literature, and only 10 patents cited more than 50 non-patent literature. It is obvious that larger the number of cited non-patent literatures lesser the number of patents. After the repetitions are removed, 2768 non-patent literature remain. After the deletion of incomplete literature and other types of literature, 1756 papers exist. According to the matching procedure, these papers match with the *SCI* database. It is found that 1172 *SCI* papers are matched successfully. After the second repetition removal based on *WoS* accession number, 1106 *SCI* papers without repetition are acquired finally.

Results and analysis

Science linkage analysis: By data collection, 214 biotechnology patents of China are found and 1106 *SCI* papers are cited by these patents, and on an average every patent cites 5.17 *SCI* papers. The number is much larger than that of other technology fields. Wen[12] found that the average number of *SCI* papers cited in chemistry, computer and communication, and mechanical in China is 1.67, 0.19 and 0.2 respectively.

Table 1. Science linkage of patents in China's biotechnology field

	Number of patents (A)	Number of NPRs cited (B)	Number of *SCI* papers cited (C)	Science linkage (C/A)
1981–1999	13	64	8	0.62
2000–2003	22	246	66	3
2004–2007	64	804	290	4.53
2008–2011	115	1767	755	6.57

Table 2. Top-ten *SCI* journals cited in China's biotechnology patents

Rank	*SCI* journals	Category	Number of papers cited
1	*Proceedings of the National Academy of Sciences of the United States of America*	Multidisciplinary sciences	52
2	*Science*	Multidisciplinary sciences	48
3	*Journal of Biological Chemistry*	Biochemistry and molecular biology	30
4	*Plant Molecular Biology*	Biochemistry and molecular biology, plant sciences	25
5	*Nature Biotechnology*	Biotechnology and applied microbiology	22
6	*Nucleic Acids Research*	Biochemistry and molecular biology	20
7	*Plant Physiology*	Plant sciences	19
8	*Gene*	Genetics and heredity	19
9	*Journal of Immunology*	Immunology	18
10	*Biochemical and Biophysical Research Communications*	Biochemistry and molecular biology, biophysics	18
10	*Lancet*	Medicine, general and internal	18

In order to know whether the reliability of China's biotechnology innovation on basic research has been strengthening or weakening with time, several different time-periods are divided to analyse the science linkage of biotechnology. Among them, the year of patent is the issued year; the year of paper is the published year. Table 1 lists the average number of *SCI* papers cited by patents in four time-periods.

Table 1 shows that the number of patents, number of NPRs cited by the patents and number of cited *SCI* papers have been increased rapidly. In the recent four years (2008–2011), the number of patents (115) is nearly ten times more than that in the first stage (1981–1999) lasting 20 years. Yet the number of NPRs has increased almost 30 times. The most outstanding is the number of cited *SCI* papers, which has increased close to 100 times.

It is obvious that China's biotechnology innovation depended little on basic research before 2000, with a science linkage of only 0.62 in 1981–1999; but the biotechnology innovation has relied more and more on basic research after 2000. The science linkage is 3 in 2000–2003, but it has increased to 6.57 during 2008–2011, twice the former. Hence, we can see that the reliability of China's biotechnology innovation on basic research presents the continuously strengthening tendency.

Journal source of cited SCI paper analysis: *SCI* papers referenced by China's biotechnology patents come from different journals. According to the number of *SCI* papers cited by patents of journals, the main journal source of these cited *SCI* papers can be found. Table 2 lists the top-ten journals and their subject categories, and the number of times they are cited. Among them, *Proceedings of the National Academy of Sciences of the United States of America*, *Science* and *Journal of Biological Chemistry* are cited most frequently. By subject category analysis, the scientific knowledge which is cited in patents is found to mainly originate from international journals, especially journals, such as *Proceedings of the National Academy of Sciences of the United States of America* and *Science*; and some professional journals on biochemistry, plant science, genetics, immunology, etc., which also have great international influence. These international journals become the major theory source of patent technology in China's biotechnology industry.

Nationality distribution of authors of SCI papers: Analysing the nationalities of authors of *SCI* papers cited by patents, we can learn the sources of the scientific knowledge of *SCI* papers cited by the patents. Figure 3 shows the nationality distribution of authors of *SCI* papers.

Figure 3 reveals that *SCI* papers referenced in China's biotechnology patents are mainly by American researchers. The cited *SCI* papers of Chinese authors' works rank second, but there is a wide gap compared with American authors' papers. The cited *SCI* papers of English authors are almost the same as those of Chinese authors, followed

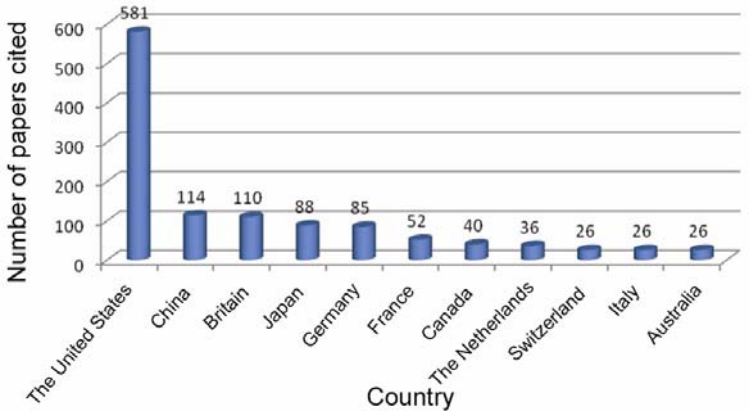

Figure 3. Nationality distribution of authors of *SCI* papers.

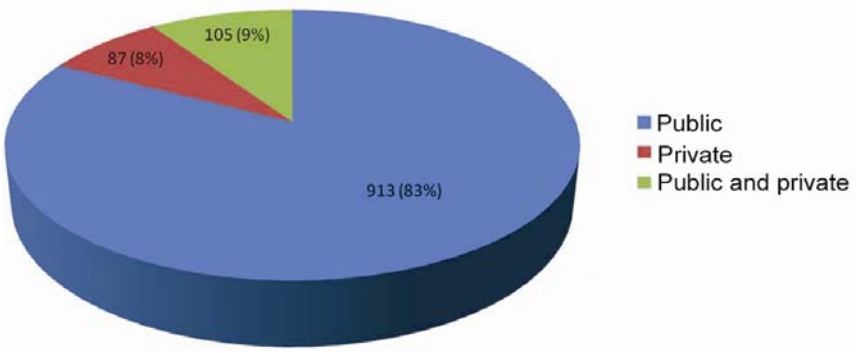

Figure 4. Reliance of China's biotechnology patents on public science.

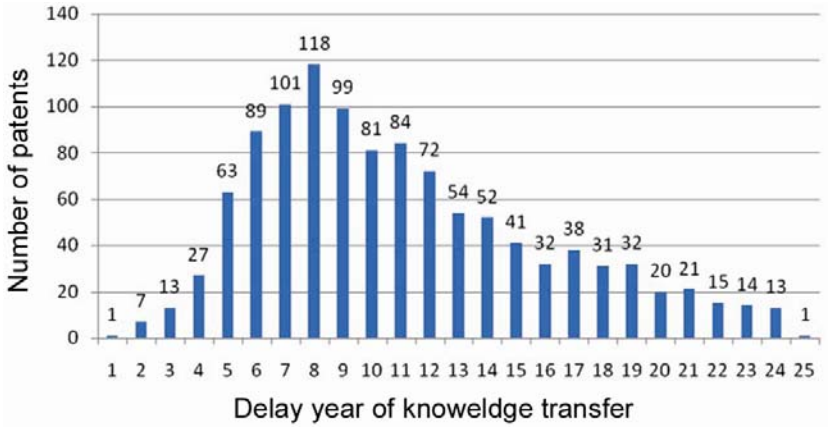

Figure 5. Knowledge transfer speed in China's biotechnology field.

by Japan, Germany, France and other countries. It should be noted that when handling statistical data, China's coverage includes the mainland China and Hong Kong. If only the number of cited *SCI* papers of the mainland China is counted, it ranks fifth with 69 papers; Hong Kong ranks sixth with 61 papers. Thus, America's basic research is the main source of technology innovation in China's biotechnology industry and China's self-capability of basic research is much lower than America's. Meanwhile, England, Japan, Germany, France and other developed countries are also important source countries for basic knowledge in China's biotechnology innovation.

Public science analysis: Through the analysis on institution categories of authors of *SCI* papers cited in patents, the source of basic research can be divided into three categories: public science, private science and public & private cooperation science. Figure 4 shows the reliance of China's biotechnology patents on public science.

Figure 4 reveals that *SCI* papers referenced in China's biotechnology patents are mainly derived from public science research, with 83% from public science (universities, medical schools, public hospitals, research institutes, charity organizations, etc.), 9% from the cooperation of public science and private science enterprises and only 8% entirely from scientific research enterprises. This is obviously higher than that of American public science in biotechnology. According to McMillan *et al.*[15], 71.6% of *SCI* papers cited in American biotechnology patents are from public science, 11.9% from the cooperation of public and private science and 16.5% from private science enterprises. It shows that the reliability of China's biotechnology innovation on public science is stronger than that of America and that public science has made a great contribution to China's biotechnology innovation and basic research in biotechnology industry in China needs the powerful support of public science.

The knowledge transfer speed: In order to know the new degree of basic knowledge which China's biotechnology patents cite, the knowledge transfer speed is calculated. Figure 5 shows that the delay year of knowledge transfer shows a positive skewed distribution (skewness = 0.626), and the eighth year is the highest point in the curve. It reflects that the eighth year is the highest frequent citation delay year from the cited scientific paper published year to the patent issued year in biotechnology. Taking the delay time from patent application to patent issued, about two years into consideration, *SCI* papers are most possibly cited in the sixth year after they published.

Conclusion

We have analysed the relationship between technology innovation and basic research. NPR analysis method was used and empirical analysis of China's biotechnology industry was done. The results showed that basic research is the important source of China's biotechnology innovation.

The patent systems of China and the United States are different. For example, there are no clearly specified requirements that references must be listed in the invention application and license in the Chinese patent system, as in the case of USA system. As a result, so far there is no content about patent references in Chinese patent data issued by the State Intellectual Property Office. Analysis on China's patent references is still lacking. We do not know to what extent China's basic research makes contribution to technology innovation in biotechnology; neither do we know to what degree China's patents depend on basic research. However, the present study takes patents that China has acquired in USA as the object. All these patents strictly conform to the demands of the US patent system. Thus the present study has revealed the relationship between the US patents invented by Chinese assignee and basic research in biotechnology field.

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