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Postprint: Research on Biotechnology Development Trends in Belt and Road Countries

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Abstract

The Belt and Road Initiative traverses the Asian, European, and African continents, connecting the dynamic East Asian economic circle, the developed European economic circle, and the vast hinterland countries and regions with enormous economic development potential in between, and will exert significant and far-reaching impacts on China's future domestic and international political, economic, cultural, and technological development. This report analyzes the foundational conditions for scientific and technological development in countries along the Belt and Road, examines the overall progress in basic research and patent technology R&D achieved by these countries in the biotechnology field, reviews the current status of biotechnology industry development and international patent deployment among Belt and Road nations, and proposes developmental recommendations for further deepening mutually beneficial and win-win cooperation between China and Belt and Road countries in the biotechnology sector.

Full Text

Preamble

A Study on the Trends of Biotechnology Development in Countries along the Belt and Road

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Abstract

The Belt and Road Initiative traverses the continents of Asia, Europe, and Africa, connecting the vibrant East Asian economic circle, the developed European economic zone, and the vast hinterland countries and regions with tremendous development potential. This initiative will exert profound and far-reaching impacts on China's future political, economic, cultural, and scientific-technological development both domestically and internationally. This report analyzes the foundational conditions for scientific and technological development in Belt and Road countries, examines the overall progress in basic research and patented technological R&D in biotechnology achieved by these nations, reviews the current state of biotechnology industry development and international patent distribution, and proposes recommendations for deepening mutually beneficial cooperation between China and Belt and Road countries in the biotechnology sector.

Keywords: Belt and Road, biotechnology, bio-economy, bioindustry

Introduction

In September and October 2013, General Secretary Xi Jinping proposed the strategic vision of building the “New Silk Road Economic Belt” and the “21st Century Maritime Silk Road,” which has attracted high attention and strong resonance from domestic and relevant countries, regions, and the global community. In March 2015, the National Development and Reform Commission, Ministry of Foreign Affairs, and Ministry of Commerce jointly issued the “Vision and Actions on Jointly Building the Silk Road Economic Belt and 21st Century Maritime Silk Road,” comprehensively explaining the logic and vision of the Belt and Road Initiative and clarifying cooperation partners and strategic directions.

The Belt and Road Initiative traverses the continents of Asia, Europe, and Africa, connecting the vibrant East Asian economic circle, the developed European economic zone, and the vast hinterland countries and regions with tremendous development potential. The northern route of the “New Silk Road Economic Belt” focuses on facilitating connectivity from China through Central Asia and Russia to Europe (the Baltic Sea); the central route aims to connect China through Central Asia and West Asia to the Persian Gulf and Mediterranean Sea; and the southern route seeks to link China to Southeast Asia, South Asia, and the Indian Ocean. The “21st Century Maritime Silk Road” extends westward from China's coastal ports through the South China Sea to the Indian Ocean and onward to Europe, while the eastward route connects China's coastal ports through the South China Sea to the South Pacific. Building upon the 65 countries along the Belt and Road, the initiative further extends to multiple advanced developed countries in Europe and the Asia-Pacific region, while domestically driving the development of northwestern, northeastern, southwestern, coastal, Hong Kong, Macao, Taiwan, and inland regions. This will have signif-

ificant and far-reaching impacts on China' s future political, economic, cultural, and scientific-technological development both domestically and internationally.

1. Biotechnology Development Foundation in Belt and Road Countries

Based on 2015 baseline data from the 65 Belt and Road countries, the total population reached 3.20 billion, accounting for 52.4% of the global population, with densely populated countries concentrated primarily in South Asia. According to 2015 World Bank statistics, the combined GDP of these 65 countries totaled US\$12.1 trillion, representing 16.3% of global GDP. Among them, 16 were high-income countries and 23 were upper-middle-income countries. Countries with per capita GDP exceeding US\$20,000 were mainly concentrated in the Persian Gulf region [Figure 1: see original paper][Figure 2: see original paper].

While economic development levels vary significantly, these countries also exhibit substantial disparities in overall scientific and technological development. For instance, in terms of R&D expenditure as a percentage of GDP, Israel, Slovenia, Singapore, and several other high-income Eastern European countries have maintained relatively high ratios in recent years (2005-2015), with Russia and other high-income Eastern European nations ranking among the top. In 2015, countries with higher proportions of high-tech exports relative to GDP were primarily located in ASEAN and Eastern Europe, led by Singapore, Vietnam, and Malaysia [Figure 3: see original paper][Figure 4: see original paper].

Regarding R&D personnel capacity, according to incomplete statistics, Israel, Singapore, Russia, and Central and Eastern European countries possess relatively large numbers of researchers and technical development personnel among Belt and Road nations [Figure 5: see original paper][Figure 6: see original paper].

In terms of overall research output capacity, countries with greater research investment and larger R&D personnel pools also demonstrate relatively stronger capabilities. Based on 2015 population figures (in millions), countries with relatively high average numbers of research publications and patent applications during 2005-2015 include Singapore, Israel, and some Eastern European nations such as Russia [Figure 7: see original paper][Figure 8: see original paper].

2. Biotechnology R&D Progress in Belt and Road Countries

According to the OECD definition, biotechnology primarily refers to technologies based on modern life sciences that combine advanced engineering techniques and principles from other foundational disciplines to modify organisms or process biological materials according to predetermined designs for producing certain products or achieving specific purposes. By application field, biotechnology can be broadly categorized into medical biotechnology (primarily for medicine,

pharmaceuticals, and clinical applications), industrial biotechnology (primarily for food, energy, manufacturing, and environmental protection), and agricultural biotechnology (primarily for crop breeding and genetic improvement).

This study conducts a bibliometric analysis of the current state of biotechnology R&D in Belt and Road countries based on research papers and invention patents. The paper analysis utilizes data from the Web of Science platform, with search strategies primarily referencing recent research reports and relevant literature, adjusted based on expert consultation. The Web of Science Core Collection data source includes journal articles indexed in the Science Citation Index Expanded (SCI-E). Patent analysis employs data from the IncoPat technological innovation intelligence platform, with search strategies primarily referencing OECD reports and relevant literature, modified according to expert consultation. The IncoPat platform includes bibliographic information on patent applications and grants from major economies worldwide, covering 105 countries, regions, and organizations.

2.1.1 Overall Situation

Over the past five years (2012-2016), Belt and Road countries published nearly 300,000 research papers in biotechnology, accounting for one-sixth of the global total in this field. Specifically, papers from Belt and Road countries in medical, industrial, and agricultural biotechnology represented 16%, 24%, and 22% of global output in their respective fields [Figure 9: see original paper].

All three subfields demonstrated steady year-over-year growth in publication numbers. Medical biotechnology had the largest publication base with stable growth (annual growth rate of 6.26%). Industrial biotechnology showed the fastest growth (8.25% annually), followed by agricultural biotechnology (7.25% annually). Belt and Road countries actively collaborated with other nations and regions, with approximately one-third of research papers published through international cooperation. Among these collaborative papers, those co-authored with the United States accounted for the largest share at 13.01% of the total, followed by the United Kingdom and Germany. China was also a major cooperation partner, with collaborative papers representing 2.41% of the total .

Belt and Road countries produced 2,290, 494, and 187 highly cited papers in medical, industrial, and agricultural biotechnology, respectively. Over 60% of these highly cited papers resulted from international collaborations with countries outside the Belt and Road region [Figure 10: see original paper]. (In the Web of Science platform, Essential Science Indicators (ESI) designates articles ranking in the top 1% globally in citation count within a specific field over the past decade as “highly cited papers.”)

2.1.2 Medical Biotechnology

From 2012-2016, India ranked first in publication volume in medical biotechnology. As shown in , while individual countries showed significant variation, the

regional distribution of research capacity was relatively balanced. Except for the five Central Asian countries, which exhibited relatively low overall research levels, and Central and Eastern Europe, which demonstrated relatively high levels, other regions showed comparable overall capacity.

India, Israel, and Poland were the three Belt and Road countries with relatively high numbers of highly cited papers in medical biotechnology, with very similar counts [Figure 11: see original paper]. In terms of the proportion of highly cited papers to total papers, Singapore had the highest ratio at 2.41%. Israel, Greece, the Czech Republic, and Hungary also achieved proportions above 2%.

2.1.3 Industrial Biotechnology

From 2012-2016, India topped the list of publication volume in industrial biotechnology, far surpassing second-ranked Iran . Geographically, the leading countries were not distributed in East Asia. India also dominated in highly cited paper production in this field, with a substantial lead, while the remaining nine countries had relatively similar counts [Figure 12: see original paper]. However, India, Iran, Turkey, and Russia showed lower proportions of highly cited papers at 0.80%, 0.67%, 0.55%, and 0.62%, respectively. Israel had the highest proportion at 2.37%, with Saudi Arabia and Singapore also exceeding 2%.

2.1.4 Agricultural Biotechnology

From 2012-2016, India led in publication volume in agricultural biotechnology, with output more than triple that of second-ranked Pakistan . Leading countries were not located in East or Central Asia. While individual variations were significant, regional patterns showed that except for the five Central Asian countries with low overall research levels and Central and Eastern Europe with relatively high levels, other regions exhibited comparable overall capacity.

India also published the most highly cited papers in agricultural biotechnology, far exceeding second-ranked Saudi Arabia [Figure 13: see original paper]. Among the top 10 countries, the remaining nine had relatively similar counts. India, Pakistan, and Iran showed lower proportions of highly cited papers at 0.99%, 0.77%, and 0.58%, respectively. Saudi Arabia had the highest proportion at 3.04%, with Singapore, the Philippines, and Slovenia also exceeding 2%.

2.1.5 Biotechnology International Cooperation

Belt and Road countries maintain close cooperation in medical biotechnology, forming a dense collaborative network among the 65 countries and with China. Singapore has the closest cooperative relationship with China, followed by Hungary, Pakistan, India, and Saudi Arabia. In industrial biotechnology, Singapore, Pakistan, India, and Saudi Arabia all have relatively close ties with China, while Egypt-Saudi Arabia, India-Saudi Arabia, Malaysia-Iran, Malaysia-Bangladesh,

and Poland-Ukraine also demonstrate strong collaborative relationships [Figure 14: see original paper].

In agricultural biotechnology, Albania and Brunei published only 3 and 2 papers respectively in 2016 without establishing cooperative relationships with other Belt and Road countries or China. All other countries engaged in bilateral or multilateral cooperation, with China-Pakistan cooperation being the closest. China also maintains strong collaborative relationships with India, Singapore, Israel, Turkey, Egypt, and Saudi Arabia. Among Belt and Road countries themselves, Egypt-Saudi Arabia cooperation is the strongest, forming a tripartite close collaboration with India [Figure 14: see original paper].

2.2.1 Overall Situation

From 2012-2016, a total of 467,342 biotechnology invention patents were filed globally, with Belt and Road countries accounting for 15,689 applications (3.4% of the global total). [Figure 15: see original paper] illustrates the annual patent application trends, showing rapid growth in industrial biotechnology patent output among Belt and Road countries during this period. While medical and agricultural biotechnology patents remained stable before 2014, they demonstrated significant growth from 2015 onward, with compound annual growth rates of 11.3% and 12.2%, respectively. Industrial biotechnology patents showed consistent growth throughout the period, achieving a compound annual growth rate of 20.2%.

lists the top 10 countries with the most patent cooperation partners across the three biotechnology fields. China engaged in patent cooperation with individual Belt and Road countries across all three domains but at relatively low levels, ranking 10th overall. Specifically, China co-filed 14 patents with 7 countries in medical biotechnology, 12 patents with 12 countries in industrial biotechnology, and only 1 patent with Israel in agricultural biotechnology.

2.2.2 Field Distribution

From 2012-2016, Belt and Road countries filed 10,683 medical biotechnology invention patents, 9,506 industrial biotechnology patents, and 880 agricultural biotechnology patents. India, Israel, Russia, and Singapore were the top four patent-producing countries across all three fields, with their combined applications accounting for 84%, 83%, and 81% of total Belt and Road patent output in medical, industrial, and agricultural biotechnology, respectively.

India dominated in all three subfields, with Russia, Israel, and Singapore ranking second through fourth in medical and industrial biotechnology, and Israel, Russia, and Singapore occupying these positions in agricultural biotechnology [Figure 16: see original paper]. Other countries in the top 10 included Malaysia, the Czech Republic, Hungary, and Greece, but each accounted for less than 5% of the total, with most below 2%.

2.2.3 International Cooperation

Visualization of patent cooperation networks across the three biotechnology fields reveals relatively weak collaboration among Belt and Road countries themselves, but stronger partnerships with scientifically advanced nations such as the United States and the United Kingdom, which serve as bridges in these networks [Figure 17: see original paper]. In medical biotechnology patents, 6 of the top 10 cooperation partners were developed countries: the United States, United Kingdom, Switzerland, Germany, France, and Sweden. In industrial biotechnology, 6 of the top 10 partners were also developed countries: the United States, Germany, Sweden, United Kingdom, France, and Australia. In agricultural biotechnology, 4 of the top 10 partners were developed countries: the United States, United Kingdom, Switzerland, and Japan.

3. Biotechnology Industry Layout in Belt and Road Countries

3.1 International Industry Layout

The Belt and Road Initiative represents a major measure for China's comprehensive opening-up under new historical conditions, providing an important platform for international scientific and technological cooperation and mutual benefit while harboring unlimited opportunities for modern technology industries. The bio-industry has become a global strategic emerging sector, with some developed countries establishing mature mechanisms and remarkable achievements. Major Belt and Road countries are also actively promoting modern bio-industry development as a new breakthrough point for economic growth.

Currently, international biotechnology output and bio-industry development remain most active in developed countries. In terms of industrial structure, Asian Belt and Road countries prioritize biomedical industries and biological resource conversion and utilization industries to drive bio-industry growth, while Central and Eastern European countries focus on biochemical and environmental protection industries, emphasizing biotechnology applications in industrial sectors. As the Belt and Road vision continues to develop, it will further facilitate the circulation and integration of relevant resources, technologies, and industries, promoting the substantial development of modern bio-industries in participating countries.

Singapore, an important participant in the Belt and Road Initiative, serves as a major global port and occupies a strategically important position in China's maritime transportation network. While Singapore's early economic takeoff relied on rapid development of electronics manufacturing, the 21st century has seen the nation attach great importance to bio-industry strategic layout, setting a goal to rank among the world's top biotechnology nations within five years and launching an ambitious drive to transform its industrial structure into a biotechnology powerhouse. Through policy incentives, tax benefits, and construction of

biotechnology industrial parks, Singapore has attracted numerous multinational biotechnology companies to establish regional headquarters, invest in manufacturing facilities, and set up R&D centers, rapidly forming industrial clusters and developing into Asia's bio-industry hub. Biotechnology has become one of Singapore's four pillar industries, with over 30 international pharmaceutical giants operating in the Biopolis research park, including AbbVie, Amgen, Baxter, Bayer, Novartis, Roche, Takeda, and GlaxoSmithKline.

Israel's biotechnology industry encompasses medical, pharmaceutical, and industrial sectors, representing one of the world's most active centers for both basic research innovation and corporate R&D activities. The country has actively pursued research in biological breeding and algal bioenergy in recent years, with its biomedical sector experiencing the most rapid growth. Israel is home to major corporations like Teva and Taro Pharmaceuticals, as well as startups such as InterPharm and Evogene. Many domestic enterprises possess core technologies, ensuring commercial success while leading frontier research and attracting substantial international cooperation opportunities. Multinational pharmaceutical companies including Johnson & Johnson, GE, Merck, and Sanofi all maintain operations in Israel.

India was among the first Asian countries to propose vigorous development of its biotechnology industry. Leveraging its abundant natural and intellectual resources, India positioned itself as a world-class biomanufacturing center in biotechnology applications at the beginning of this century and has achieved remarkable accomplishments in recent years. Characterized by high internationalization, rapid growth, and strong innovation, India's biotechnology industry has become Asia's largest biomedical R&D outsourcing base and maintains high export volumes of agricultural biotechnology products.

Southeast Asian countries such as Thailand and Malaysia possess abundant biomass resources and favorable investment environments. In March 2015, the Chinese Academy of Sciences launched the "Belt and Road" Microbial Resources Utilization Technology Cooperation Network, signing 5-year comprehensive cooperation memoranda with Thailand's National Center for Genetic Engineering and Biotechnology (BIOTEC) and the Thailand Institute of Scientific and Technological Research (TISTR), agreeing to establish joint research centers to collaborate on microbial strain preservation, microbial big data, and research on yeasts, lactic acid bacteria, and entomopathogenic fungi, thereby promoting comprehensive cooperation in microbiology between China and Thailand.

Central and Eastern European countries have developed distinctive biochemical and bio-environmental industries. For example, through meticulous policies, regulations, and robust data and technical support, Poland has achieved remarkable results in environmental technologies including wastewater and solid waste management, energy efficiency, bioenergy, and clean industrial processing.

Overall, Belt and Road countries include both biotechnology giants like India with production advantages and vast markets, as well as innovative nations like

Singapore and Israel possessing cutting-edge technologies and favorable business environments. However, they lack globally dominant biotechnology powerhouses that lead both technologically and commercially. Promoting comprehensive technological exchange and production capacity cooperation between China and Belt and Road countries can effectively leverage complementary advantages in resources, technology, human capital, and markets to pursue win-win development.

Under the guidance of the Belt and Road development strategy, China's biotechnology industry is actively expanding various forms of regional and overseas cooperation. At the end of 2010, Angel Yeast established a factory in Egypt with a total investment of US\$75 million and an annual production capacity of 15,000 tons of dry yeast, creating over 300 local jobs. In September 2015, Angel Yeast officially began construction on its Russian facility with a total investment of 463 million RMB and an annual design capacity of 20,000 tons, which will become Russia's most advanced yeast factory upon completion. In May 2014, Shandong Jintai Biochemical Group invested US\$130 million to build a citric acid plant in Kazincbarcika, northeastern Hungary, with an annual design capacity of 100,000 tons of citric acid and salts, creating 160 local jobs. In September 2014, Anhui BBKA Biochemical Co., Ltd. laid the foundation for a citric acid fermentation factory in the Szolnok Industrial Park in Hungary, with a total investment of US\$134 million and an annual design capacity of 60,000 tons. These initiatives will help optimize the production capacity structure of certain domestic industries, facilitate the export of domestic enterprises' equipment and technology, fully utilize abundant overseas resources, capture international markets, achieve "both ends overseas" production and sales models, and promote healthy industrial growth.

3.2 International Patent Layout

From 2012-2016, Belt and Road countries received 8,203 medical biotechnology invention patent applications, 10,608 industrial biotechnology applications, and 736 agricultural biotechnology applications, with annual reception numbers showing an increasing trend. India alone accounted for over 60% of applications across all three fields, ranking first, followed by Russia and the Philippines [Figure 18: see original paper][Figure 19: see original paper].

Based on applicant nationality information for these patents, Russia and India ranked among the top two positions across all three fields. However, the remaining eight countries in the top 10 were primarily non-Belt and Road nations, with the United States, Canada, Japan, Switzerland, and Germany being the main extraterritorial entities seeking biotechnology patent protection in Belt and Road countries.

In comparison, China filed only 109 invention patent applications in Belt and Road countries during this period, including 51 in medical biotechnology, 53 in industrial biotechnology, and 5 in agricultural biotechnology, failing to rank in

the top 10 in any field. This indicates that China's patent protection efforts in Belt and Road countries remain relatively weak compared to countries like the United States, Canada, and Japan [Figure 19: see original paper].

4. Conclusions and Development Recommendations

In terms of basic research progress in biotechnology, Belt and Road countries published nearly 300,000 research papers in medical, industrial, and agricultural biotechnology over the past five years (2012-2016), representing one-sixth of global output. Industrial biotechnology demonstrated the fastest growth at 8.25% annually. Approximately one-third of research papers were published through extraterritorial international collaboration (with non-Belt and Road countries), with over 60% of highly cited papers resulting from such collaborations. China ranks among the major cooperation partners for Belt and Road countries, with collaborative papers accounting for 2.41% of their total output. India, Israel, Poland, Singapore, and the Czech Republic are among the most prolific publishers of biotechnology research papers in the region.

Regarding patented technological R&D progress, Belt and Road countries filed 15,689 patent applications in the three biotechnology fields over the past five years, representing 3.4% of the global total. Industrial biotechnology patents showed the most significant growth trend, with an annual growth rate of 20.2%. India, Israel, Russia, and Singapore are the leading patent applicants among Belt and Road countries, with their combined applications exceeding 80% of the regional total. However, due to the exclusive nature of patent applications, extraterritorial collaborative applications remain limited, with only 27 patents co-filed with China.

The biotechnology industries in Belt and Road countries possess certain resource and technological foundations, including production powerhouses like India with vast markets and innovative nations like Singapore and Israel with cutting-edge technologies and favorable business environments. However, the region currently lacks globally dominant biotechnology leaders. Meanwhile, Belt and Road countries represent an important region for international biotechnology patent layout, with India, Russia, and the Philippines being the primary recipients of biotechnology patents. The United States, Canada, and Japan are the main extraterritorial entities seeking patent protection in these countries, while China's patent layout remains relatively weak with only 109 applications.

Overall, biotechnology development in Belt and Road countries shows an upward trend, and mutually beneficial cooperation with China is gradually deepening. As the Belt and Road vision continues to evolve, it will further facilitate the circulation and integration of resources, technologies, and industries, promoting substantial development of modern bio-industries in the region. However, China still faces certain competitive challenges in its development cooperation with Belt and Road countries. It should seize historical opportunities, adopt forward-looking strategies, and expand cooperation pathways to further

deepen scientific and technological collaboration, enhance mutual connectivity, conduct joint research and production capacity cooperation, and actively promote regional scientific, technological, and socio-economic development.

First, China should focus on major national and regional economic development strategic plans to further deepen high-level scientific and technological exchanges and cooperation in biotechnology. This includes strengthening information sharing, academic exchanges, technological cooperation, and education and training with Belt and Road countries; formulating targeted scientific and technological innovation action plans; and deepening high-level exchanges and cooperation through various measures such as scientific exchanges, personnel mobility, joint laboratory establishment, construction of scientific organization alliances, and technology incubation centers.

Second, China should align with the actual needs of its biotechnology industry development to promote industrial upgrading and optimization and deepen supply-side structural reforms. This involves improving the adaptability and flexibility of supply structures in response to demand changes, actively resolving overcapacity issues, promoting healthy industry economic development, accelerating the improvement of industrial cluster construction, cultivating a group of internationally competitive representative enterprises, and building bilateral characteristic industry international cooperation parks to guide leading enterprises in establishing overseas cooperation parks.

Finally, China should target international market characteristics, strengthen strategic choices for biotechnology industry development, and adopt actionable advantageous strategies. As globalization accelerates, China should innovate cooperation models and formulate reasonable international cooperation priorities and strategies tailored to different countries' and regions' resource endowments, industrial foundations, and regional economic development characteristics to enhance open cooperation levels in key areas. For countries and regions with solid technological foundations, China should focus on talent and technology acquisition and academic exchanges while strengthening product and service output targeted at market demands. For emerging economies in development, China should emphasize academic exchanges and technological cooperation, leverage complementary advantages, and jointly conduct industrial investment, technology research, and market expansion, focusing on equipment and human resource output. For countries and regions with technological gaps, China should focus on exploring market opportunities and cultivating industrial chains, considering technology output of non-core intellectual property and resource sharing and joint development.

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