

Technological Revolution, Disruptive Technologies and Smart Agriculture Postprint

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Abstract

This paper first elaborates on the concept of technological revolution and its enabling conditions, proposes and analyzes endogenous and exogenous agricultural disruptive technologies and their differences, particularly introduces the concept of cross-boundary technologies and demonstrates their exogenous impact on agricultural technological progress. It then analyzes the characteristics of smart agriculture technology as the epitome of cross-boundary technologies, the replacement of traditional agricultural production technologies and modes by smart agriculture, and the relationship between smart agriculture and rural economic transformation. Based on this, the paper discusses the problems facing the development of smart agriculture in China. Finally, it puts forward targeted policy recommendations for promoting disruptive technological innovation and smart agriculture development, including strengthening research and development of key disruptive core technologies, reforming the existing agricultural higher education system, promoting industrialized agricultural research and development of cross-boundary technologies, and implementing smart agricultural production in high-standard farmland and large-scale breeding farms.

Full Text

Technological Revolution, Disruptive Technology and Smart Agriculture

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Abstract: This paper first elaborates on the concept of technological revolution and its requisite conditions, proposing and analyzing both endogenous and exogenous agricultural disruptive technologies and their differences. In particular, it introduces the concept of transboundary technology and demonstrates

its exogenous impacts on agricultural technological progress. The paper then examines the characteristics of smart agriculture technology—as the quintessential embodiment of transboundary technology—its substitution for traditional agricultural production technologies and methods, and its relationship with rural economic transformation. Based on this analysis, the paper discusses the challenges facing the development of smart agriculture in China. Finally, it proposes targeted policy recommendations to promote disruptive technological innovation and smart agriculture development, including strengthening research and development of key disruptive core technologies, reforming the existing agricultural higher education system, promoting industrial agricultural R&D for transboundary technologies, and implementing smart agriculture production in high-standard farmland and large-scale farming operations.

Keywords: technological revolution; disruptive technology; transboundary technology; smart agriculture

Since the 1990s, with the rapid global development and commercial application of genetically modified crops, the term “new agricultural technological revolution” has frequently appeared in Chinese publications and government documents [1]. However, aside from GM crop varieties replacing conventional ones, a comprehensive “technological revolution” that disrupts entire agricultural technology systems or production methods has yet to emerge. This paper analyzes the characteristics of technological revolutions and modern smart agriculture technologies to propose future directions for agricultural technological revolutions and policy safeguards China should adopt for smart agriculture technology innovation and development.

2. Agricultural Technological Revolution, Disruptive Technology, and Science

A technological revolution refers to a comprehensive, fundamental transformation of technologies in major human domains and their associated production and lifestyle patterns, driven by the invention and innovation of certain key core technologies. Researchers have termed the technological system and production-lifestyle changes caused by inventions such as the steam engine, electricity, and electronic information technology as the three technological revolutions in modern history [2]. A technological revolution must satisfy three conditions: First, the direct application of key disruptive core technologies must bring about changes in industries, production methods, or lifestyles. Second, the application of these key disruptive core technologies must generate a series of innovations that substitute for existing technologies, with these new technologies becoming primary production technologies or components of the technological system. Third, the application of key disruptive core technologies must render existing industrial technologies inadequate for production needs, necessitating entirely new technological innovations to adapt to these core technologies.

An agricultural technological revolution is the process whereby key disruptive core technology innovations applied to agricultural production drive a series of technological innovations adopted in production. For example, the invention and promotion of dwarf and lodging-resistant crop varieties brought about widespread adoption of mechanical technology, thereby transforming crop production methods. The extensive cultivation of dwarf and fertilizer-tolerant varieties made it possible to increase fertilizer application to raise crop yields, leading to the substitution of chemical fertilizer technology for traditional manure technology. Meanwhile, increased irrigation measures to raise crop yields per unit area, along with fertilization techniques, caused an increase in crop diseases and pests, driving innovations in pest control technologies.

Key disruptive core technologies for agricultural technological revolutions can be either endogenous disruptive technologies generated within agriculture or exogenous new technologies applied across boundaries. Endogenous disruptive technologies from within agriculture refer to technological indicators that can fundamentally change original technologies—such as productivity improvements—overturn the economic or social necessity of adopting original technologies, and completely replace them. For example, the dwarf variety technology mentioned earlier was an endogenous disruptive technology induced within agriculture to address lodging problems (due to tall stalks) that limited yield potential when soil fertility was continuously increasing in China, South Asia, and Latin America at that time [3]. This technology's adoption drove the development and updating of machinery, fertilizer, pesticide, and other technologies, as well as changes in production methods. Endogenously driven key disruptive technologies are not necessarily core technologies of a technological revolution. For instance, GM crop variety technology, which began commercial cultivation in the 1990s, was a technology induced within agriculture to solve pest control problems, with the potential to substitute for other variety technologies. However, because it did not fundamentally change the existing technological system or production methods, it constitutes a single-item disruptive technology rather than a key core technology of a technological revolution.

Unlike endogenous disruptive technologies, key disruptive core technologies for cross-boundary application originate from non-agricultural fields. After introducing such technologies into agricultural production, their breakthrough characteristics in significantly improving agricultural production efficiency drive the renewal of existing technologies and technological systems, and may even change original production methods or lifestyles. Since these technologies come from non-agricultural fields, the changes they cause in original agricultural technologies and systems are exogenously driven—that is, the resulting technological revolution is exogenous. For example, with the development of smart sensor technology and its application in agricultural production, it will fundamentally change the traditional production method that relies on experience and visual observation for agricultural operations, accordingly driving the intelligent transformation of irrigation, fertilization, and harvesting technologies, as well as factory-based operations in agricultural production. This cross-boundary tech-

nology' s application in agriculture represents a completely exogenously driven technological revolution. It should be noted that cross-boundary applied exogenous technologies may also be single-item non-technological-revolution key core technologies. For example, plastic film technology' s application in agriculture significantly increased crop yields and provided possibilities for facility agriculture development. However, this cross-boundary technology was single-item and did not drive innovation across entire crop production technologies or systems. Therefore, it belongs to single-item non-technological-revolution key core technologies applied across boundaries.

Transboundary technology for exogenous application refers to technologies whose original invention and innovation were for non-agricultural fields and have nothing to do with agricultural industry uses. It is important to note that differences exist in how endogenously generated and exogenously applied cross-boundary agricultural new technologies (including both disruptive and single-item technologies) drive agricultural technological progress. Endogenously driven technology inventions and innovations result from long-term observation within agriculture, identifying and systematically researching problems affecting production development. These R&D efforts have clear technological innovation objectives from the start, and the agricultural technological progress they drive has distinctly predictable endogenous characteristics. In contrast, exogenously introduced cross-boundary technologies, whose inventions and innovations are not from within agriculture, have effects on agricultural production that were not considered by agricultural professionals before their introduction. Therefore, the agricultural technological progress they bring after introduction has distinctly exogenous (unanticipated) driving characteristics.

3. Smart Agriculture and Technological Revolution

As the quintessential embodiment of transboundary technology, smart agriculture technology will be the key disruptive core technology driving a new round of scientific, industrial, and rural transformation. Smart agriculture refers to the application of Internet of Things technology to traditional agriculture, using sensors and software to control agricultural production through mobile or computer platforms, making traditional agriculture more "intelligent" [4,5]. It is a cross-boundary agricultural application technology or technological system centered on smart sensors and linked through mobile network platforms [6]. Smart sensors perceive and recognize animal and plant growth and their environments, transmitting this information via the Internet to back-end information processing systems. These systems automatically generate relevant agricultural operation instructions based on scientific parameters and "command" field management activities for crops (such as irrigation and fertilization) or feeding and environmental control for animals, achieving fully automated operations throughout the agricultural production process.

Smart agriculture technology can solve the problem of traditional agriculture

relying on experience for production. Traditional agricultural production mostly involves farmers determining the growth status of plants and animals based on experience and conducting agricultural operations accordingly. For example, crop production from land preparation and fertilization to field management (including pest control) and harvesting primarily depends on farmers' experience or visual observation, with few precise measurements or monitoring using instruments. This experience-based production requires continuous on-site observation by labor. Since different "observers" have varying knowledge and capabilities, observation results differ, leading to agricultural operations that are not necessarily yield- or profit-maximizing measures. Smart agriculture technology replaces human observation and experience with smart sensors, achieving precise perception of data on plant and animal growth status and production environments, fundamentally solving the problem of experience-based agricultural operations and truly realizing scientific agricultural production.

Smart agriculture technology will fundamentally change traditional agricultural production methods and enable factory-based production. Smart agriculture production mainly relies on sensor technology, using scientific instruments to perceive agricultural production and environments and back-end data analysis systems based on science to achieve automated management of farming activities. In this context, agricultural production will realize modern factory-based production based on intelligent mechanical technology, completely transforming traditional agricultural production methods. Future development of new plant and animal varieties and related technologies will also adapt mutually to smart agriculture development. As basic agricultural production materials, improved varieties will have breeding objectives that adapt to the needs of related production operations under smart agriculture development conditions. For example, traits and standards for plant and animal varieties that adapt to smart sensor cognition and perception, and growth and reproduction processes and standards that adapt to smart machinery and agricultural operations. Meanwhile, as breeding technology for improved plant and animal varieties develops and progresses, smart agriculture technology will also evolve toward more accurately perceiving characteristics of new improved varieties, thereby improving agricultural production yield potential and efficiency.

Smart agriculture will also drive revolutionary rural transformation. Under conditions of factory-based production, farmers engaged in smart agriculture will transform production activities into operations of related machinery and intelligent control equipment. Their daily work (production activities) will become position work on assembly lines, like workers, forming non-differentiated occupational labor intensity between worker and farmer. Under these conditions, true integration between rural and urban areas will be achieved, completing the revolutionary transformation of the rural economy.

4. Development of Smart Agriculture in China and Its Challenges

Smart agriculture will drive a new round of agricultural technological revolution. To meet this technological transformation, some countries have begun formulating a series of science and technology policies [5]. The United States, Europe, Japan, and other countries and regions have seized the opportunities of the digital revolution, introducing initiatives such as the “Big Data Research and Development Initiative,” “A UK Strategy for Agricultural Technology,” and “Agriculture 4.0,” attempting to widely apply modern information technology throughout agriculture and equip agriculture with digital technology [5]. However, most countries internationally have proposed future development plans under the name of digital agriculture. This difference in terminology determines distinctions in development direction and path. Digital agriculture emphasizes the digital transformation of the entire agricultural production and circulation industry chain, focusing on using information technology to transform agriculture and emphasizing production and circulation management across the entire agricultural industry chain. Smart agriculture, in contrast, emphasizes technological updating of agricultural production processes, particularly the intelligent substitution and transformation of human labor.

China was the first country to develop Green Revolution technology [7,8] and is a pioneer in applying modern revolutionary technologies in agriculture. As early as the late 1950s, China globally pioneered the first Green Revolution variety, “Aijiaonante,” for large-scale production application, and in the 1970s first achieved three-line matching for hybrid rice [8]. These technologies not only improved China’s rice productivity and changed agricultural production methods [9,10] but also led global agricultural production, especially rice production technology progress. Notably, with the application of transboundary technologies centered on information technology, China has again become a global pioneer in agricultural technology revolutions, leading a new round of world agricultural technological revolution. For example, drone technology, pioneered in developed countries, has been more widely applied to pest control and other agricultural production in China; smartphone-based online trading technology (mobile e-commerce), first developed in the United States, has been further developed in China, making it the country with the most extensive online sales of agricultural products and food in the world, thereby transforming agricultural production and management methods.

It must be particularly noted that smart agriculture-related technologies centered on smart sensors are already mature, with some technologies widely adopted in developed countries. Taking the United States as an example, while adopting modern GM varieties, it uses satellite remote sensing technology to provide farmers with comprehensive technical services and real-time production solutions from land preparation, fertilization, pest monitoring and control, to harvesting, according to the cultivation management requirements of different varieties. In animal production, besides large-scale farming, it has achieved

fully automated management of temperature, humidity, and environment in farming facilities. However, these technologies have only partially realized intelligent applications.

China's application of smart agriculture technology based on artificial intelligence is still in its infancy. At present, China has achieved large-scale industrial application of agricultural drones for pest control. Some enterprises have begun applying sensor technology in high-end fruit production and livestock and aquaculture farming, and a few have even started using sensor technology for high-end soilless and facility agriculture production. These smart agriculture technology applications have all demonstrated good economic and social benefits, showing great potential for production application. However, application of smart agriculture technology based on artificial intelligence remains in the exploratory stage.

Smart agriculture technology is not only the future development direction of agricultural production but also an inevitable trend for China's agricultural development. With the development of modern science and technology, intelligent sensor technology is already very mature and will become a "cheap" technology for substituting labor in the future. For example, smart sensor technology can achieve real-time monitoring of soil nutrients, moisture, and environment, with related components being very inexpensive; modern satellite remote sensing technology can monitor soil nutrient and moisture content in real time, monitor the occurrence degree of pests and diseases, and use this as a basis for management using modern artificial intelligence machinery. As population aging intensifies, smart agriculture technology will be China's inevitable choice for substituting agricultural labor and achieving agricultural modernization.

Notably, as an agricultural application of transboundary technology, smart agriculture technology centered on intelligent sensing technology has not, unlike the agricultural machinery technology revolution, chemical technology revolution, and Green Revolution technology, been dominated by agricultural scientists in its R&D. According to the authors' investigation, to date, very few core smart agriculture technology R&D projects in China have involved researchers from agricultural technology fields. Most existing artificial intelligence technology and equipment have been developed by researchers from non-agricultural professional fields. In fact, China's current agricultural education and R&D system lacks institutions and personnel compatible with smart agriculture development. The vast majority of agricultural universities offer traditional agricultural majors, with few researchers' projects and research directions related to smart agriculture technology applications. Meanwhile, university and research institution teams currently engaged in agricultural remote sensing research mostly conduct resource investigation studies. At the same time, engineering universities and research institutions engaged in remote sensing and artificial intelligence research lack corresponding agricultural professionals, and a research system for the close integration of transboundary technology agricultural applications has not yet been formed.

5. Policy Recommendations

Based on the current status and existing problems of disruptive technology and smart agriculture technology development in China, this paper proposes policy recommendations to strengthen key disruptive core technology R&D, reform the agricultural higher education system, promote industrial agricultural R&D for transboundary technologies, and standardize and scale smart agriculture production.

- (1) **Strengthen key disruptive core technology R&D to seize the international high ground.** Current international agricultural technology development trends indicate that a new round of agricultural technological revolution is arriving, including smart agriculture technologies and biotechnology throughout the entire agricultural production chain. In the smart agriculture technology field, China already possesses and masters the vast majority of core components and other technologies for smart agriculture applications. What is currently lacking are related agricultural-specific equipment. Future R&D priorities for smart agriculture technology should focus on developing agricultural intelligent sensor technology modules and agricultural remote sensing technology modules. In the biotechnology field, China's GM technology R&D is in the world's first tier [11]; in gene editing technology, although China does not hold key core technology patents for CRISPR/Cas9, it possesses similar technologies capable of gene editing operations; and in key core technologies for fields such as biological synthesis that may cause a new round of agricultural technological revolution in the future, related research is synchronized with the world. Therefore, sustained government and enterprise R&D investment in these fields is the foundation for China to seize the international high ground and achieve corner overtaking.
- (2) **Reform the existing agricultural higher education system to cultivate smart agriculture technology talent.** The reason why the aforementioned transboundary technologies have been rarely applied in agriculture is that research institutions and enterprises engaged in these technologies' R&D rarely understand or pay attention to agriculture, and agricultural researchers lack corresponding knowledge. Therefore, taking effective measures to cultivate smart agriculture professionals is a pressing task. Recommendations include three aspects: First, on the basis of talent introduction, integrate relevant professional faculty in agricultural universities and related institutions, establish smart agriculture majors, and cultivate professionals who directly participate in smart agriculture production and industry or provide technical services; Second, add smart agriculture application courses to traditional agronomy majors, transform traditional professional teaching content, and expand knowledge of smart agriculture applications and their production performance; Third, conduct smart agriculture technology training for grassroots agricultural technical personnel to equip them with basic capabilities to use and provide smart

agriculture technical services to farmers and related enterprises.

- (3) **Promote reform of agricultural research institutions to drive industrial agricultural R&D and rapid application of transboundary technologies.** Smart agriculture technology is a typical transboundary technology for agricultural application. Among existing R&D units and enterprises, not only do units engaged in sensor and information technology development lack knowledge about applying these technologies in agricultural production, but professionals engaged in agricultural technology R&D also lack knowledge about which agricultural production links can apply more advanced transboundary technologies for substitution. Therefore, based on the current separation between agricultural technology specialties and component technology specialties, integrate research talents engaged in these two fields to conduct R&D on smart agriculture professional technology, while encouraging related enterprises to attract talents with backgrounds in both agricultural components and agricultural specialties to conduct related technology development. This is the direction for future reform of agricultural research institutions.
- (4) **Following the principle of tackling easier tasks first, prioritize implementing smart agriculture production in already-built high-standard farmland and large-scale farming operations, and promote nationwide based on accumulated experience.** According to the authors' investigation, aside from the large-scale application of agricultural drones, China already has mature technologies in core areas applicable to smart agriculture, including soil and crop sensors, remote sensing, pest identification and monitoring, livestock biometrics, mechanized farm networks, and agricultural product traceability systems. Through targeted R&D of agricultural equipment, these can be applied in agricultural production. For example, temperature and humidity sensors for agricultural use cost only about 10% of the annual investment in agricultural machinery per unit area, while application of these technologies in agriculture will save approximately 80% of costs in corresponding production links. Moreover, these investments are fixed assets that can be reused. In fact, China can currently conduct smart agriculture production trials, demonstrations, and implementation in farmland with better production conditions and standardized large-scale livestock and aquaculture farms. Since 2009, the Chinese government has invested heavily in high-standard farmland construction, which has already built relatively complete farmland irrigation systems and other facilities that can be slightly modified to adopt technologies such as intelligent irrigation, intelligent fertilization, and intelligent pest control. Standardized large-scale livestock and aquaculture farms also have conditions suitable for priority application of sensor technology for healthy farming.

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