Technology Revolution, Disruptive Technologies, and Smart Agriculture Post-Print

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Abstract

This paper first elaborates on the concept of technological revolution and its necessary conditions, proposes and analyzes endogenous and exogenous agricultural disruptive technologies and their differences, and particularly introduces the concept of cross-boundary technologies while demonstrating their exogenous impacts on agricultural technological progress. It then examines the characteristics of smart agriculture technology as the epitome of cross-boundary technologies, its substitution for traditional agricultural production technologies and modes, and its relationship with rural economic transformation. On this basis, the paper discusses the challenges confronting the development of smart agriculture in China. Finally, it offers 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 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 necessary conditions, proposes and analyzes endogenous and exogenous agricultural disruptive technologies and their differences, and particularly introduces the concept of transboundary technology while demonstrating its exogenous impacts on agricultural technological progress. It then examines the characteristics of smart agriculture technology—as the epitome of transboundary technologies—along with its substitution effects on traditional agricultural production technologies and methods, and its relationship with rural economic transformation. Building on this foundation, the paper discusses the challenges facing China' s smart agriculture development. Finally, it proposes targeted policy recommendations to promote disruptive technological innovation and smart agriculture development, including strengthening R&D of key disruptive core technologies, reforming the existing agricultural higher education system, promoting industrial R&D of 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

Introduction

Since the 1990s, with the rapid global development and commercialization of genetically modified crops, the term "new agricultural technology revolution" has frequently appeared in Chinese publications and government documents [1]. However, beyond GM crop varieties replacing conventional ones, a true "technological revolution" that overturns the entire agricultural technology system or production paradigm has not materialized. Based on an analysis of the characteristics of technological revolution, this paper examines modern smart agriculture technologies and proposes future directions for agricultural technological revolution, along with policy safeguards that China should adopt for smart agriculture technology innovation and development.

This paper is organized into four sections. First, it outlines the concept and necessary conditions of technological revolution, analyzes endogenous and exogenous agricultural disruptive technologies and their differences, and particularly examines the exogenous impacts of transboundary technologies on agricultural technological progress. Next, it analyzes the characteristics of smart agriculture technology, its substitution of traditional agricultural production technologies and methods, and its relationship with rural economic transformation. The paper then discusses challenges in China' s smart agriculture development. Finally, it proposes targeted policy recommendations.

2. Agricultural Technological Revolution and Disruptive Technologies

Technological revolution refers to comprehensive, fundamental transformations in major fields of human technology and related production and lifestyles driven by the invention and innovation of certain key core technologies. Researchers have identified three technological revolutions in modern history: the invention of the steam engine, the discovery of electricity, and the development of electronic information technology [2]. A technological revolution must satisfy three conditions: first, direct applications of the key disruptive core technology must bring about changes in industries, production methods, or lifestyles; second, the application of this key core technology must generate a series of innovations that substitute for existing technologies, with these new technologies becoming primary production technologies or part of the technological system; and 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 production requirements.

Agricultural technological revolution refers to the process where key disruptive core technology innovations applied to agricultural production drive a series of technological innovations in production practices. For example, the invention and promotion of dwarf, lodging-resistant crop varieties drove widespread adoption of mechanization and transformed crop production methods. The extensive cultivation of dwarf, fertilizer-tolerant varieties made it possible to increase fertilizer application to boost crop yields, leading to the substitution of chemical fertilizer technology for traditional manure. Meanwhile, increased irrigation and fertilization measures to raise per-unit yields caused a rise in crop diseases and pests, driving innovations in pest control technologies.

Key disruptive core technologies for agricultural technological revolution can be either endogenous disruptive technologies generated within agriculture or exogenous technologies applied across boundaries. Endogenous disruptive technologies from within agriculture fundamentally alter the technical indicators of existing key production technologies—such as productivity improvements—disrupting the economic or social necessity of previous technologies and completely replacing them. For instance, the dwarf variety technology mentioned earlier was an endogenous disruptive technology induced within agriculture when soil fertility continued to increase in countries like China and traditional tall varieties' lodging susceptibility limited yield potential [3]. This technology' s adoption drove the development and updating of machinery, fertilizer, and pesticide technologies, as well as changes in production methods.

In contrast, exogenously applied transboundary technologies are those originally invented and innovated for non-agricultural fields with completely unrelated purposes. When introduced into agricultural production, their breakthrough characteristics in improving agricultural productivity drive the renewal of existing technologies and systems, even changing production methods or lifestyles. Since these technologies originate outside agriculture, their cross-boundary introduction causes exogenously driven changes to agricultural technology and systems —representing an exogenous technological revolution. For example, the application of smart sensor technology in agriculture will fundamentally transform production methods that rely on experience and visual observation, driving intelligent transformation of irrigation, fertilization, and harvesting technologies, as well as factory-style agricultural operations.

It is important to note that endogenously generated and exogenously introduced agricultural technologies (including both disruptive and single technologies) differ in their contributions to agricultural technological progress. Endogenously driven technological inventions and innovations emerge from long-term observation within agriculture, identifying and systematically addressing production constraints. These R&D efforts have clear technological innovation objectives from the outset, and the resulting agricultural technological progress has distinctly predictable endogenous characteristics. In contrast, cross-boundary technologies invented and innovated outside agriculture have effects that agricultural professionals could not have anticipated before their introduction. Consequently, the agricultural technological progress they bring exhibits distinctly exogenous (unanticipated) characteristics.

3. Smart Agriculture and Technological Revolution

As the epitome of transboundary technologies, smart agriculture 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 via mobile or computer platforms, making traditional agriculture more "intelligent" [4,5]. It is a transboundary agricultural application technology or technological system centered on smart sensors and connected through mobile network platforms [6]. Smart sensors perceive and recognize crop and livestock growth and their environments, transmitting this information via the internet to backend information processing systems. Based on relevant scientific parameters, these systems automatically generate operational instructions for farm management activities (such as irrigation and fertilization) or animal feeding and environmental control, enabling fully automated operations throughout the agricultural production process.

Smart agriculture technology can solve the problem of experience-based agricultural production. Traditional agricultural production overwhelmingly relies on farmers' experience to assess crop and livestock conditions and conduct farm operations accordingly. From land preparation and fertilization through field management (including pest control) to harvest, crop production depends primarily on farmers' experience or visual observation, with few precise measurements or monitoring using instruments. This experience-based production requires continuous on-site observation, and because different "observers" have varying knowledge and capabilities, observation results differ, leading to farm operations that do not necessarily maximize yield or profit. Smart agriculture technology replaces manual observation and experience with scientifically precise data through accurate perception of crop, livestock, and environmental conditions, fundamentally solving the problem of experience-based operations and truly achieving scientific agricultural production.

Smart agriculture technology will fundamentally transform traditional agricultural production methods, enabling factory-style production. Smart agriculture relies primarily on sensor technology, using scientific instruments for precise perception of agricultural production and environmental conditions, and automated management based on scientific backend data analysis systems. Under this paradigm, agricultural production will achieve modern factory-style production based on intelligent machinery technology, completely revolutionizing traditional agricultural production methods. Future developments in crop and livestock varieties and related technologies will also adapt to smart agriculture. As the most basic agricultural production input, improved varieties will have breeding objectives oriented toward smart agriculture development to meet operational requirements—for example, developing traits and standards compatible with smart sensor recognition and perception, and growth and reproduction processes suited for smart machinery and farm operations. Meanwhile, as breeding technology advances, smart agriculture technology will evolve toward more precise perception of new variety characteristics to further enhance yield potential and efficiency.

Smart agriculture will also drive revolutionary rural transformation. Under factory-style production conditions, farmers' agricultural activities will become operation of agricultural machinery and intelligent control systems. Daily work (production activities) will become assembly-line positions, similar to industrial workers, creating undifferentiated occupational labor intensity between farmer and worker. This will enable true integration between rural and urban areas, completing revolutionary rural economic transformation.

Smart agriculture will spur a new round of agricultural technological revolution. To embrace this transformation, Western countries have begun formulating a series of science and technology policies [5]. The United States, Europe, and Japan have seized opportunities from the digital revolution, launching 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 differences in development direction and pathways. Digital agriculture emphasizes digital transformation of the entire agricultural production and circulation chain, focusing on using information technology to transform agriculture and emphasizing management of the entire production and circulation chain. Smart agriculture, in contrast, emphasizes technological innovation in the production process itself, particularly intelligent replacement of manual technologies in the production phase.

It is particularly noteworthy that smart agriculture-related technologies centered on smart sensors have matured, with some already widely adopted in Western developed countries. In the United States, for example, while adopting modern GM crop technology, satellite remote sensing is used to provide farmers with comprehensive technical services and real-time production solutions throughout the entire process—from land preparation, fertilization, pest monitoring and control, to harvest—tailored to different varieties' cultivation requirements. In livestock production, besides large-scale farming, fully automated management of temperature, humidity, and environment in production facilities has been achieved. However, these technologies have only partially realized intelligent application.

China' s application of smart agriculture technology based on artificial intelligence is still in its exploratory stage. Currently, 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 operations, and a few have even started using sensor technology for high-end soilless and facility agriculture production. These smart agriculture technology applications have demonstrated good economic and social benefits and show tremendous potential. However, smart agriculture technology applications based on artificial intelligence remain in the exploratory phase.

Smart agriculture technology represents not only the future direction of agricultural production but also an inevitable trend for China' s agricultural development. With the development of modern science and technology, smart sensor technology has become very mature and will become a "cheap" technology for replacing labor in the future. For example, modern sensor technology enables real-time monitoring of soil nutrients, moisture, and environmental conditions, with related components being very inexpensive. Modern satellite remote sensing can monitor soil nutrient and moisture content in real time, monitor pest occurrence levels, and enable management using modern artificial intelligence machinery. As population aging intensifies, smart agriculture technology will be China' s inevitable choice for replacing agricultural labor and achieving agricultural modernization.

Notably, as a transboundary agricultural application, smart agriculture technology centered on smart sensors has not, like the agricultural machinery revolution, chemical technology revolution, and Green Revolution, been dominated by agricultural scientists in its R&D. According to our investigations, to date, very few core smart agriculture technology R&D projects in China have involved agricultural technology researchers. Existing artificial intelligence technology and equipment have been developed by researchers from non-agricultural fields. In fact, China' s current agricultural education and R&D system lacks institutions and personnel suited to smart agriculture development. The vast majority of agricultural universities maintain traditional agricultural programs, with few researchers working on topics or directions related to smart agriculture applications. Existing university and research institution teams engaged in agricultural remote sensing research mostly conduct resource survey studies, while higher education and professional training in this area are virtually nonexistent. Meanwhile, engineering universities and research institutions engaged in remote sensing and artificial intelligence research lack corresponding agricultural expertise, and a research system integrating transboundary technology with agricultural applications has yet to form.

5. Policy Recommendations

Based on the current status and challenges of disruptive technologies and smart agriculture development in China, this paper proposes the following policy recommendations: strengthening R&D of key disruptive core technologies; reforming the agricultural higher education system; promoting industrial R&D of transboundary technologies; and implementing standardized, large-scale smart agriculture production.

(1) Strengthen R&D of key disruptive core technologies to seize the international high ground. From current international trends in agricultural science and technology development, fields that may trigger a new round of agricultural technological revolution include smart agriculture technology throughout the entire production chain and biotechnology. In smart agriculture, China already possesses and masters most core components and technologies for smart agriculture applications. What is currently lacking are agriculture-specific equipment. Future research priorities should focus on developing agricultural smart sensor technology and agricultural remote sensing technology modules. In biotechnology, China' s GM technology R&D ranks in the world' s first tier [11]; in gene editing, although China does not hold key patents for CRISPR/Cas9, it possesses similar technologies for gene editing operations. In synthetic biology —a field that may trigger a new round of agricultural technological revolution —China' s research is synchronized with global efforts. Sustained government and enterprise R&D investment in these fields is essential for China to seize the international high ground and achieve leapfrog development.

(2) Reform the existing agricultural higher education system to cultivate smart agriculture technology talent. The limited application of transboundary technologies in agriculture is partly because R&D institutions and enterprises working on these technologies have limited understanding of agriculture, while agricultural researchers lack relevant knowledge. Therefore, cultivating technical and industrial professionals for smart agriculture applications is imperative. Three measures are recommended: First, based on talent recruitment, integrate relevant faculty in agricultural universities and related institutions to establish smart agriculture programs that cultivate professionals directly engaged in smart agriculture production, industry, or technical services; Second, add smart agriculture application courses to traditional agronomy programs to transform traditional curricula and expand knowledge of smart agriculture applications and production performance; Third, provide smart agriculture technology training to grassroots agricultural technical personnel to equip them with basic capabilities for using and providing smart agriculture technical services to farmers and enterprises.

(3) Promote reform of agricultural research institutions to accelerate industrial R&D and rapid application of transboundary technologies. Smart agriculture technology is a typical transboundary agricultural application technology. Among current R&D institutions and enterprises, those engaged in sensor and information technology development lack knowledge about agricultural applications, while agricultural technology R&D personnel lack knowledge about which agricultural production segments could benefit from more advanced transboundary technologies. Therefore, based on the current separation between agricultural technology specialties and component technology specialties, integrating research talent from both fields to conduct smart agriculture technology R&D, while encouraging enterprises to attract talent with backgrounds in both agricultural components and agricultural specialties for related technology development, represents the future direction for agricultural research institution reform.

(4) Following the principle of tackling easier tasks first, prioritize implementing smart agriculture production in established high-standard farmland and large-scale farming operations, then promote nationwide based on experience gained. According to surveys, aside from the already large-scale application of agricultural drones, China possesses mature technologies in core areas such as soil and crop sensors, remote sensing, pest identification and monitoring, livestock biometrics, mechanized farm networks, and agricultural product traceability systems. Targeted R&D of agricultural equipment would enable application in agricultural production. Temperature and humidity sensors for agricultural use cost only about 10% of annual per-unit-area agricultural machinery investment, yet these technologies can save approximately 80% of costs in corresponding production segments, with these investments being fixed assets that can be reused. In fact, China is fully capable of initiating smart agriculture production trials and demonstrations in well-conditioned farmland and large-scale livestock farms. Since 2009, the Chinese government has invested heavily in high-standard farmland construction, which has established relatively complete irrigation systems and equipment that can be readily adapted for smart irrigation, smart fertilization, and smart pest control. Similarly, standardized large-scale livestock and aquaculture farms also provide favorable conditions for priority application of sensor technologies for healthy farming.

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Note: Figure translations are in progress. See original paper for figures.