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Article

The Impact of Internet Knowledge Spillover Effects on Rural Human Capital in China: The Role of Digital Literacy

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Abstract: The digital revolution has become the internet an indispensable instrument for the dissemination of information. This is particularly evident in rural China, where it significantly contributes to the development of human capital. This study investigates the effect of online information dissemination on rural human capital, particularly focusing on the role of digital literacy on agricultural productivity. Agriculturalists proficient in computer usage may access valuable information, such as market data and agronomic advice, facilitating improved decision making and enhanced operational efficiency. This, thus, aids them in tackling various challenges encountered by rural regions. The research employed a mixed methods approach, using national statistics, surveys, and comprehensive interviews to assess the influence of internet based knowledge on rural human capital. The findings indicate that instructing farmers in the proper use of digital platforms can enhance their productivity and foster sustainable development in rural regions. The implementation of targeted training programs and appropriate standards is essential, as evidenced by issues such as inadequate infrastructure and insufficient digital competencies. These difficulties must be resolved to facilitate the unobstructed flow of information, enhance agricultural practices, and provide new possibilities in rural regions. We provide critical insights on how digital literacy may bridge the digital divide and enhance economic development in rural regions by facilitating access to online resources.

Keywords: Knowledge spillover effects; rural human capital; digital literacy; agricultural productivity; digital transformation.

Introduction

The internet has become an essential tool for information sharing in the digital revolution of the global economy. Ahmed (2017) explores the role of information and communication technology (ICT) in facilitating knowledge spillovers, which are critical for human capital development. However, this study mainly focuses on general economies and lacks insights into rural contexts in China, where infrastructure and digital literacy levels vary. These spillovers have notably improved rural human capital and led to a steady rise in agricultural output (Paunov & Rollo, 2016). As such, understanding the impact of internet driven knowledge spillovers on rural human capital, particularly the critical role of digital literacy, is vital (Chang et al., 2016).

Laut et al. (2023) examine the rapid transmission of knowledge and skills through online platforms in rural environments. While their study highlights the broad effects of internet driven knowledge spillovers, it does not fully address regional disparities, which limits its applicability in contexts such as rural China, where infrastructure and digital literacy levels vary considerably. This study extends Laut et al.'s framework by

investigating how local factors, such as infrastructure availability and digital literacy, influence the effectiveness of online knowledge sharing in improving agricultural productivity.

In rural regions, geographic isolation and limited educational resources can impede access to information; however, the internet remains readily accessible (Serrano & Cabrer, 2004). Ali (2026) argues that digital literacy allows farmers to obtain crucial agricultural technologies and market information, thereby offering a competitive edge. However, their research does not adequately address the infrastructural limitations and regional disparities in digital skills that hinder the adoption of digital technologies in economically disadvantaged rural areas. Enhanced digital literacy facilitates information accessibility and lays the groundwork for its effective utilization (Eklund & Pettersson, 2019).

Farmers in Zhejiang's 'Taobao villages' have utilized e-commerce platforms such as Taobao to directly market their crops to consumers, resulting in increased sales and earnings. However, in underprivileged regions, the potential for this model to expand remains uncertain due to persistent infrastructure challenges. The Alibaba Research Institute reports that by 2020, over 5,400 'Taobao villages' existed, significantly contributing to the growth of e-commerce sales and average household income (Navon, 2010). Farmers in Guangxi have utilized live streaming platforms such as Douyin (TikTok) and Kuaishou to promote their products, enhancing their visibility and value. These examples illustrate how farmers may leverage the internet to generate income and enhance their agricultural operations when they possess the requisite skills. Infrastructural challenges and disparities in training and digital skills persistently hinder the effectiveness of these platforms in certain rural areas (Liao et al., 2025). This underscores the essential function of digital literacy in enabling the dissemination and efficient application of information within agricultural practices. The information spillovers facilitated by the internet are crucial for improving agricultural productivity in the digital economy (Yu et al., 2022). These spillovers enhance human capital development and increase agricultural efficiency, especially in rural areas (Zhao et al., 2021).

This research investigates two main questions: (1) How do internet driven knowledge spillovers influence the development of human capital in rural areas? (2) What role does digital literacy play in this process? The objective of this research is to elucidate the flow of information in rural communities and provide theoretical foundations for policy development aimed at improving digital literacy and agricultural productivity. This will be achieved through the use of case studies and qualitative analysis.

Literature Review

1. Theoretical Framework of Internet Knowledge Spillover Effects

Knowledge spillover theory provides a framework for understanding its potential impact on the enhancement of rural human capital within the context of the digital economy (Acs et al., 2013). However, their model primarily applies to general economic contexts and does not fully account for the specific challenges faced in rural China, where infrastructure and digital literacy levels vary significantly. Knowledge spillover refers to the intangible transfer of information and knowledge within networks. In the agricultural sector, the internet plays a crucial role in disseminating technologies and best practices through various informational platforms (Tian et al., 2021). While Tian et al.'s study underscores the broad influence of the internet, it does not adequately address the infrastructural and digital literacy challenges that impact farmers in rural China. This effect is reflected not only in the transfer of knowledge but also in fostering information sharing, strengthening social networks, and accelerating the evolution and updating of knowledge.

The progress of internet technologies has greatly enhanced access to information in rural regions (Kaila & Tarp, 2019). However, Arbine (2024) highlights the challenges of digital access and skills in underserved regions, such as Tawau, Malaysia. Social media platforms enable farmers to quickly acquire valuable knowledge and apply it in agricultural practices, thereby improving their skills in farming techniques. In addition to saving time, this distribution of information also enhances the accuracy with which technology is utilized. For instance, farmers who adopted innovative agricultural techniques and participated in online training experienced a more than 20% increase in crop output in the short term (Yang et al., 2023). This evidence indicates that internet knowledge not only boosts agricultural output but also optimizes resource

allocation and decision making processes, thereby facilitating the efficient distribution of information (LoPiccalo, 2021). Moreover, this progress is driven by the naturally evolving knowledge ecosystem among farmers, rather than solely relying on individual skill improvement. Through the network, experience and creativity are rapidly shared, fostering the continuous development of rural social networks and the ongoing enhancement of agricultural practices. In addition to significantly increasing agricultural output, the knowledge flow system established through the internet has laid a strong foundation for the long term growth of human capital (Song et al., 2021).

2. Digitalism and Agricultural Productivity

Bagaeva and Ivanov define digital literacy as the ability to effectively utilize digital technology. Nonetheless, their definition primarily addresses general competencies that facilitate the utilization of digital technologies. The text does not address the applicability of these skills in rural areas where infrastructure and internet access may vary significantly (Bagaeva & Ivanov, 2021). This capability includes effective information management and application, along with fundamental computer operations (Wang & Qu, 2023).

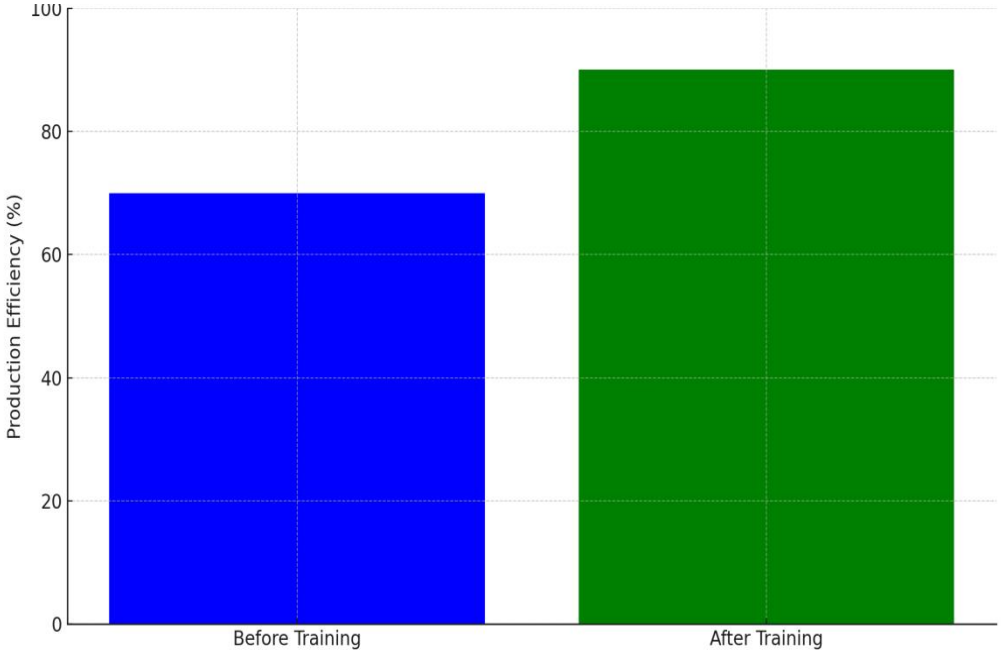

Figure 1. Impact of digital literacy training on agricultural production efficiency
Data source: Wang and Ran (2022)

Individuals residing in rural regions recognize the significance of enhanced digital literacy for the modernization and increased productivity of agriculture (Zhou et al., 2023). The rapid advancement of digital technology offers opportunities and challenges for traditional agriculture, highlighting the importance of fostering digital literacy to improve agricultural competitiveness. Rajkhowa and Qaim's study highlights the importance of digital literacy for agricultural competitiveness; however, it does not consider the unique challenges faced in rural China, such as infrastructure limitations and varying levels of digital skills.

In precision farming, enhanced digital literacy plays a crucial role in facilitating farmers' adoption of innovative agricultural technologies (Sendra, 2023). Daberkow and McBride (2003) illustrate that precision farming technologies, including soil sensors and satellite data, can enhance yields and decrease water consumption. Nonetheless, their research is grounded in the U.S. context, leaving the relevance of these findings to rural China, characterized by differing levels of digital literacy and infrastructure, uncertain. Research in China indicates that farmers who combined digital literacy training with agricultural management software for data analysis achieved an 18% improvement in output efficiency (Shang et al., 2021). Several studies indicate that farmers with higher digital literacy can produce 20% to 30% more than their less digitally

literate counterparts (Vecchio et al., 2020).

Empirical research has demonstrated that improved agricultural output and resource management are strongly influenced by higher digital literacy. In addition to enhancing technical skills, digital literacy enables farmers to effectively acquire knowledge and share resources (Klerkx et al., 2019). Through digital channels, farmers can quickly access crucial information, such as market prices, weather forecasts, and agricultural technology developments, which helps them make more accurate production decisions and minimize avoidable losses. Sinha reports a 38% improvement in crop planting accuracy and a reduction in meteorological losses through the use of digital channels. This study was conducted in India, and its findings may not be entirely applicable to the varied conditions present in rural China (Sinha, 2022). Research on Brazilian (2019) coffee growers utilizing digital technology for market pricing data indicated a 15% increase in income. The findings indicate that digital literacy, especially regarding resource efficiency and decision making accuracy, enhances agricultural output.

The relationship between digital literacy and agricultural output can be examined from several perspectives, with key factors including technology accessibility and education levels (Zhang et al., 2023). Digital literacy and agricultural output are closely linked to the accessibility of technology. The extent to which farmers can increase their digital literacy and effectively implement digital technologies in agriculture depends largely on how easily they can access these technologies. Smart agricultural tools and reliable internet access allow farmers to obtain agricultural advice, weather data, and current market information. In recent years, significant progress has been made in rural China in the spread and use of digital technologies, which has provided strong incentives for increasing agricultural output.

Sichuan Province, in particular, has made remarkable strides in agricultural digital transformation. In 2020, the degree of agricultural digitization in Sichuan reached 38.3%, surpassing the national average of 37.9%. Although Sichuan's agricultural output from information technology was 20.02%, slightly lower than the national average (Gong et al., 2024), the application of information technology in agricultural production still presents opportunities for improvement. Moreover, enhanced access to digital agricultural tools has helped farmers in Sichuan increase food production.

In the Inner Mongolia Autonomous Region, farmers have seen income increases as internet coverage expands. A 1% increase in broadband coverage results in a 0.11% increase in farmers' income, and a 1% increase in mobile phone usage leads to a 0.07% rise in income (Li, 2024). These statistics demonstrate how technological accessibility directly improves farmers' digital literacy, which in turn significantly boosts agricultural production. Zhejiang Province, a leading proponent of digital agriculture, has successfully integrated e-commerce platforms with agricultural product sales through the 'Taobao Village' model, resulting in significant income growth for farmers. In 2021, the per capita disposable income of farmers in Zhejiang reached 35,247 yuan, effectively narrowing the rural urban income gap and highlighting the major role of digital technology adoption in increasing farmers' incomes (Xiaoyan et al., 2024). Similarly, farmers in the Guangxi Zhuang Autonomous Region have expanded their sales channels and increased the visibility and added value of their products by selling directly to consumers through platforms like Douyin (TikTok) and Kuaishou, further underscoring the importance of digital literacy in enhancing agricultural output (Liu & Liao, 2024).

Digital literacy is significantly influenced by education levels and regional disparities in infrastructure, both of which impact farmers' digital skills and agricultural productivity in China. Farmers in Eastern China generally have higher digital literacy due to the region's more advanced economy and the greater availability of educational resources, which facilitate the widespread adoption of digital technologies. The 'Digital Village' program, recently launched by the government of Fujian Province, aims to enhance farmers' expertise in digital agricultural technologies. As a result, farmers in Fujian experienced an 18% increase in average income due to the introduction of advanced agricultural tools and farmer education programs. Additionally, digital agriculture training has enabled Fujian farmers to gain better access to agricultural data, leading to a 22% increase in production.

In contrast, the Western regions continue to face significant challenges. A lack of educational resources has resulted in lower digital literacy among farmers in these areas. Financial and geographical constraints have

hindered the adoption and distribution of digital technologies. Despite the recent introduction of digital agricultural training in Qinghai Province, farmers' educational attainment remains insufficient. In 2020, Qinghai's agricultural digitalization rate was only 19.4%, significantly lower than in other provinces. The increases in agricultural output in Qinghai have been modest, particularly with regard to the adoption of modern agricultural technologies and access to agricultural information. Research shows that, in contrast to the 25% output increase seen in the eastern provinces, farmers in Qinghai who received digital agriculture training increased their output by just over 14% (Liu & Zhou, 2023).

Methodology

This research employed a mixed methods approach to examine the impact of internet enabled knowledge spillovers on rural human capital and the importance of digital literacy in enhancing agricultural productivity. To present a comprehensive overview of the research participants, we collected both qualitative and quantitative data. A survey was conducted with 500 farmers in rural China, including regions like Guangxi and Zhejiang. The survey inquired about farmers' proficiency with digital tools, their frequency of internet use for farming, and their views on how digital technology affected their income and productivity. Along with the survey, 30 in depth interviews with farmers were done to learn more about their experiences with digital literacy and the problems they face while using digital tools for farming.

We utilized both primary and secondary data from national and provincial research on digital literacy and agriculture. The Alibaba Research Institute and the China Internet Network Information Center (CNNIC) were crucial sources that contextualized the primary data and validated its authenticity. We employed descriptive statistics and regression analysis to examine the relationship between digital literacy and agricultural productivity in the quantitative data. The qualitative data was subjected to thematic analysis to identify key themes including digital literacy, obstacles to adoption, and the effects of information spillovers on agricultural practices. This mixed methods study examines the impact of digital literacy on rural human capital and agricultural productivity. It employs case studies, questionnaires, interviews, and data analysis.

The Findings

1. Rural Human Capital in China

Rural human capital in China's composition and features indicate both many possibilities and problems. Education level, skills training, health condition, and social capital comprise the key elements here. Despite increased national investment in rural education in recent years, significant problems remain, particularly regarding the level of education in rural areas. Generally lacking resources, rural schools also have a relative dearth of skilled teachers, which lowers the general level of education of the rural labour force when compared to cities. The 'China Rural Human Resources Survey Report' claims that whereas the statistic for metropolitan areas is 10.3 years, the average years of education for rural labourers are just 6.5 years. This disparity not only affects farmers' knowledge accumulation and capacity for innovation but also somewhat limits the increase of agricultural output. Second, a major component influencing rural human capital is the lack of skill development. Although some farmers have developed their agricultural abilities recently, generally rural workers still suffer a gap in systematic training in contemporary agricultural technologies and information based skills. According to national polls on rural workers, only roughly thirty percent of farmers have gotten official vocational training. This percentage is far lower than the rate of high skill training in metropolitan regions, which presents challenges for rural workers in adjusting to agricultural modernisation, therefore influencing agricultural output.

Moreover, rural human capital depends much on health condition. Generally lacking medical resources and insufficient infrastructure, rural communities produce lower overall health levels than metropolitan ones. The 'National Rural Health Survey Report' claims that the incidence of chronic diseases is higher among rural people and their average health levels are much lower than those in cities. Poor health not only reduces output but may also cause production interruptions and financial losses from sick absence among workers. Higher health levels of employees have been linked to far higher productivity and decreased likelihood of missing

work due to illness, so enhancing agricultural output. Thus, raising the quality of rural human capital depends critically on bettering healthcare facilities and the public health system in rural areas.

Table 1: Analysis of internet knowledge spillover on rural human capital enhancement

Channels	Influential Factors	Outcomes
Internet Based Information Acquisition	Online Courses	Increase in Agricultural Knowledge by 10% to 20%)
	Webinars	Faster Knowledge Dissemination and Accumulation
Knowledge Exchange	Agricultural Platforms	Improved Practical Skills and Innovation Awareness
	Online Communication Communities	Enhanced Agricultural Productivity
Barriers	Weak Infrastructure	Barriers to Information Access
	Limited Network Coverage	
	Lack of Digital Literacy	
Improvement Measures	Policy Support and Training	Enhanced Ability to Apply Information Technology

An rising number of rural people are gaining access to plenty of knowledge via the internet, therefore creating a new type of knowledge spillover effect as internet technology continues to proliferate and its ability to introduce various information distribution mechanisms increases. Two key avenues mostly affect rural human capital by this knowledge spill over impact. On the one hand, the internet offers several ways for knowledge acquisition, including webinars and online courses that help knowledge to be distributed and accumulated. Modern agricultural technologies, market trends, and policy information can be obtained by farmers using these approaches which provide speedier, more extensive, and less expensive benefits than more conventional approaches. Conversely, the internet promotes knowledge sharing among many entities, including agricultural companies, research and development centres, and farmers. This interactivity improves the application capability of rural human capital as well as speeds the transmission of information.

Though the information spillover effect of the internet presents chances for enhancing rural human capital, its effect is not homogeneous. Accessing outside knowledge is still greatly hampered in some rural places by inadequate infrastructure, poor network coverage, and low digital literacy. Figure 2 shows how degrees of digital literacy and internet coverage affect agricultural output. Agricultural production increases dramatically as these two measures show, suggesting that rural economic growth benefits from the improvement in information infrastructure and digital literacy. Thus, a major goal is raising digital literacy among rural people by means of better acquisition, interpretation, and application of digital knowledge. Governments and pertinent businesses must so actively participate in efficient policy assistance and training programs in this setting.

By means of methodical, multi-level training, the capacity of rural communities to utilise information technology should be enhanced, therefore fostering a new inclusive digital education system. Another good way to improve rural human capital is investigating public private cooperation options. Resource sharing can be accomplished by creating cooperation bridges between the government and online businesses, therefore advancing the effective spread of knowledge. The knowledge spillover effect of the internet not only creates fresh opportunities for enhancing rural human capital but also helps knowledge to be communicated and exchanged, therefore promoting changes in agricultural output.

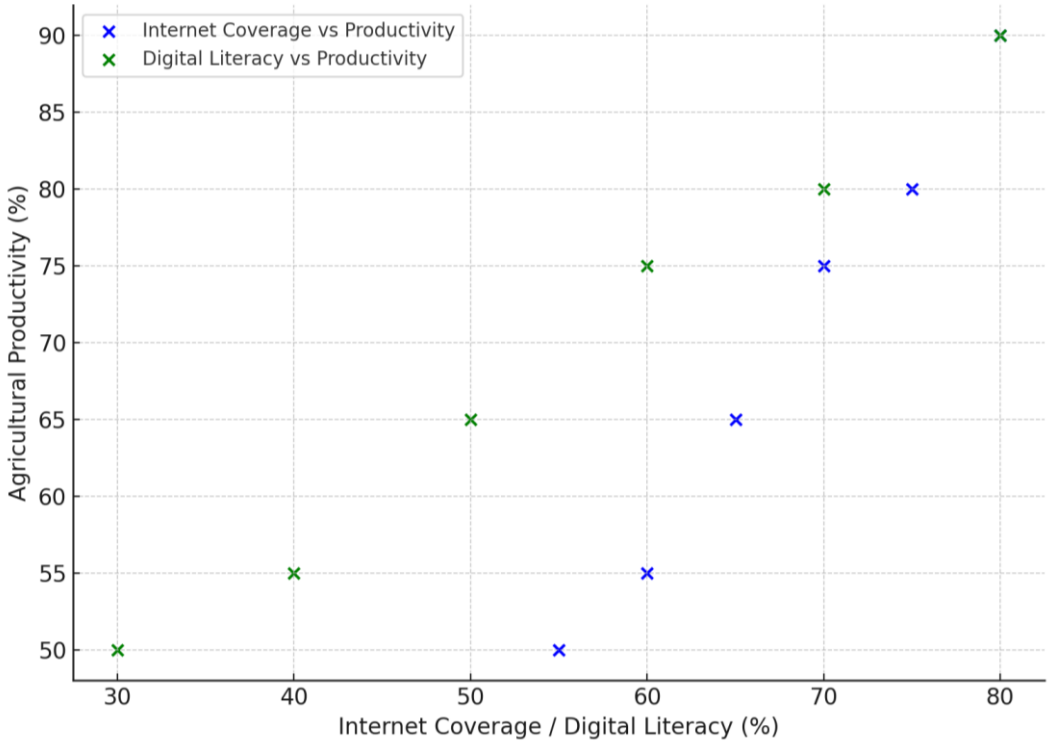

Figure 2. Internet coverage & digital literacy vs agricultural productivity
Data source: Wang & Sun (2023)

Actually, the development of rural human capital depends far more on the whole influence of external elements including the policy environment, economic structure, and socio cultural atmosphere than on internal elements including education levels and skill training. Deeper exploration of such effects is possible using the 'Five Forces Model.' From the standpoint of the policy environment, government assistance and incentive programs usually directly influence the growth of rural human capital. For example, the national 'Rural Revitalisation Strategy' seeks to enhance infrastructure and public services thereby encouraging the introduction and retention of talent in rural areas. On the other hand, poorly executed policies or ones that contradict local requirements could cause rural human capital to be lost and declining. Changes in macroeconomic policy, including changes in fiscal expenditure, could reduce investments in rural education and skill development, which surely limits the growth of human capital.

2. The Impact of Internet Knowledge Spillover on Rural Human Capital

Facilitating the transfer of online knowledge is essential, especially regarding its influence on rural human capital. These methods include social media, online courses, forums, and WeChat public accounts. This helps farmers become more digitally literate and makes it easier for them to quickly share knowledge and skills. Farmers may use the internet to learn about new farming technology, market trends, and ways to farm, which will help them improve their skills in production and management. The internet is now widely used, which has lowered the cost of getting information. This has made it easier for more rural people to use outside knowledge resources and improve their skills. Given the link between digital literacy levels and agricultural output, one can develop a mathematical model to assess the effect of online knowledge leak on agricultural productivity. Denoting digital literacy as L and agricultural output as P, the link between these two variables could be shown by the following formula,

$$Y = \beta_0 + \beta_1 L + \epsilon$$

Here, the constant denotes the marginal effect of digital literacy on agricultural output while the term expressing random error is used. By means of regression analysis on the pertinent data, we can examine how changes in digital literacy impact rural human capital and subsequently agricultural output.Knowledge building for rural areas is closely related to the efficiency and efficacy of the complete agricultural production process in addition to reflecting the enhancement of individual skill levels. The internet serves as a distribution channel that facilitates rapid knowledge transfer and efficient idea sharing through online platforms and social networks. This form of education facilitates rural laborers' access to innovative technologies and concepts associated with agricultural productivity.

The 'China Farmers Digital Agriculture Training Program' shows participants new planting techniques and market sales skills using online learning tools. Program participants displayed notably better performance in market response time and production decision making than non program participants ($p<0.05$). This example illustrates the significant impact of effective knowledge accumulation on agricultural productivity, promoting rural economic development by enhancing the skill levels of rural populations. Figure 3 illustrates the changes in internet access, digital literacy, and agricultural production from 2018 to 2023. Improved internet access and digital literacy correlate with increased agricultural productivity, highlighting the lasting impact of the digital revolution on rural economic development.

Figure 3. Internet coverage, digital literacy, and agricultural productivity (2018–2023)
Data source: IIMedia (2024)

By analyzing recent data on rural laborers' digital literacy, internet penetration, the number of rural internet users, and agricultural productivity, we can clearly identify the key factors and mechanisms behind successful cases. Specifically, data from 2018 to 2023 show a significant improvement in the digital literacy levels of rural residents in China. In 2018 and 2020, the digital literacy score for rural residents was 35.1, but by 2021, this score dropped to 18.6, before rising to 43.6 in 2023, indicating notable fluctuations and improvements in digital literacy over recent years. The discrepancies are likely due to national policy support for digital rural development, which has improved farmers' digital skills and innovative thinking through agricultural internet technologies and related training programs. The digital literacy gap between urban and rural populations underscores the urgent need to enhance digital skills development in rural areas. This highlights the necessity of advocating for policies that foster digital progress. The percentage of individuals utilizing the internet in rural regions increased from 55.9% in 2019 to 60.5% in 2023, with projections indicating a rise to 66.5% by December 2024. This trend indicates an increasing utilization of information technology in rural areas. This facilitates access to information for rural workers and provides farmers with

diverse perspectives. Consequently, farmers collectively acquire essential knowledge, encompassing agricultural technologies, market trends, and policy developments.

Case studies in China indicate that digital literacy training programs have markedly enhanced rural human capital. Programs like the 'Ministry of Agriculture and Rural Affairs' Digital Agriculture Promotion Project' and the 'National Farmers Digital Literacy Improvement Program' provide specialized training to assist farmers in utilizing digital technologies. These programs have greatly enhanced farmers' ability to independently adopt new technologies, thereby increasing agricultural output. These efforts illustrate how improving digital literacy facilitates knowledge acquisition and its practical application, creating a virtuous cycle of growth and development.

3. Strategies for Enhancing Digital Literacy

Policy Support and Training Systems

The government must implement specific programs designed to enhance rural digital literacy. Initially, the identification of digital skill deficiencies and requirements in rural regions should be conducted through research and data analysis. A 2021 poll indicated that more over 60% of rural workers possessed inadequate awareness of digital technologies, thereby impacting market participation and productivity. Therefore, the government should give money and resource allocation high importance in order to establish a special training fund to support projects on the growth of digital skills. Moreover required to mix resources and incorporate the newest digital technologies is cooperation with colleges, vocational training programs, and technology companies, so increasing the relevance and adaptability of the training. Furthermore, the government might support successful cases by means of rural e-commerce pilot communities, hence increasing the involvement of rural people in the digital economy.

The basis of increasing rural digital literacy, particularly in connection to the spill over impacts of online information, is establishing and putting a good training program into use. Training materials have to be somewhat close to the real needs of rural communities. First demand analysis should identify farmers' shortcomings in using digital tools by considering local cultural backgrounds and economic reality to ensure the training courses are targeted. For example, whereas in more developed places there would be a requirement to grasp e-commerce platform software, in some locations farmers might be not comfortable running telephones. Customised training courses can thus significantly increase the training success rate. Designed to precisely specify training objectives, content, and evaluation criteria, the training system should be built to include a 'training evaluation model' so enabling farmers to acquire basic digital skills or improve their use of agricultural management software, so guiding later content and approaches. Content wise, the training should focus on pragmatic needs such agricultural meteorology, market information, and internet sales to make sure farmers may fast utilise the knowledge obtained in their production operations. Together with local agricultural technology promotion stations and rural cooperatives, different strategies including face to face instruction, online courses, and group discussions should be applied during implementation to improve involvement and acceptance so promoting a positive environment of resource sharing.

Exploring Public Private Partnership Models

The government could actively collaborate with internet companies in rural areas by utilizing public private partnership (PPP) models to bridge the digital divide, stimulate economic growth, and improve infrastructure. For example, the government can partner with internet firms like Alibaba and Tencent under the 'Digital Village' initiative to co-invest in network infrastructure, enhancing fiber optic connectivity and expanding wireless coverage. These efforts provide rural communities with a foundation for acquiring digital knowledge and skills, thereby significantly improving network connectivity (Zhang & Bao, 2023). The government must leverage technological support from companies to establish digital training courses, thus expanding opportunities for online learning and skill development, ultimately increasing digital literacy in rural areas.

One exemplary public private partnership in Zhejiang Province is the 'Digital Village' project. Through collaboration between the government and Alibaba, network coverage in rural areas was improved, and multi-

tiered training programs were developed to address varying levels of digital literacy among local residents. These programs, ranging from basic mobile phone usage to e-commerce applications, facilitated the gradual enhancement of farmers' digital skills. As such, the government should use this effective experience to support more concentrated and methodically planned training programs. The government should improve cooperation with businesses to support projects like the Ningbo Digital Agriculture Demonstration Park, so allowing farmers to acquire modern farming technologies and use Agricultural Management Software (AMS) to improve output efficiency (Li et al., 2019). To address the digital gap among older rural populations, the government could promote the establishment of Family Intergenerational Learning (FIL) initiatives. These programs empower younger generations to assist older individuals in acquiring digital skills, thus bridging the digital divide and facilitating the intergenerational transfer of digital competencies (Cheng et al., 2021). Therefore, the government should support the development of this innovative model to ensure the simultaneous enhancement of digital skills across all generations in rural areas.

Discussion

This study reveals important insights into the impact of internet driven knowledge spillovers on rural human capital and agricultural productivity, highlighting the role of digital literacy in improving farming practices. The findings suggest that the internet acts as a key tool for providing rural populations with essential information on agricultural technologies, market trends, and management strategies, which has notably enhanced farmers' decision-making abilities and operational efficiency. However, this transformation is not uniform across all regions, and significant disparities in access to digital tools and infrastructure persist.

Our research highlights the significance of digital literacy as a catalyst for efficient information dissemination. More digitally literate farmers are better at using internet resources to seek farming help, learn about the market, and improve their output. Farmers in places like Zhejiang, where digital literacy and infrastructure are high, have effectively used digital technology for e-commerce, which has helped them get more exposure in the market. This has led to more crops being grown and higher incomes. These positive outcomes align with the findings from 'Taobao villages' and other digital agricultural initiatives, which have demonstrated the capacity of online platforms to foster rural economic development. The study indicates that the impact of digital literacy is significantly diminished in underdeveloped regions, where infrastructure and digital literacy remain in nascent stages of development. Agriculturalists in regions such as Qinghai and Inner Mongolia have been unable to fully capitalize on internet facilitated knowledge spillovers due to limited access to high speed internet and a scarcity of digital training programs. The disparities among areas indicate the necessity for a more nuanced strategy in digital literacy programs that considers the infrastructural and socio-economic conditions of each locality.

The deficiency in digital literacy and infrastructure is particularly apparent in the ongoing challenges faced by rural farmers in utilizing digital technology. A significant portion of individuals in more developed regions may utilize digital platforms for agriculture; yet, many individuals remain disadvantaged due to their geographic location and financial resources. The gap in access highlights a major limitation of our study: while the overall potential of digital literacy to improve agricultural productivity is clear, its effectiveness is heavily reliant on regional infrastructure and the availability of digital resources. PESTLE was used to investigate knowledge spillover context. This study found that politics, the economy, society, technology, legislation, and the environment affect rural digital literacy. In certain areas, the political atmosphere has helped digital literacy efforts expand, while in others, a lack of official support and investment in infrastructure has slowed progress. Social factors, such as educational achievement and regional attitudes towards technology, have also influenced the effectiveness of digital training programs.

These findings show that improving digital literacy alone won't close the gap between rural and urban agricultural productivity. We need a plan that includes both improving digital literacy and building infrastructure. Policy proposals should include specific training programs designed to meet the unique needs of farmers in different areas, as well as significant investments in digital infrastructure to provide equitable access to digital resources. To fully take use of the potential of internet driven information spillovers to

improve rural human capital and encourage sustainable agricultural expansion, these core problems must be fixed.

Conclusion

We examined the impact of digital literacy on agricultural productivity in rural China through internet driven knowledge spillovers. Digital platforms provide farmers with vital information on agricultural practices, market trends, and decision making resources. However, the profit levels generated by these networks differ among farmers. The effectiveness of these platforms is optimized when the infrastructure is robust, internet access is widespread, and the local population has technological proficiency. Regions like Zhejiang in China, recognized for robust infrastructure and a population proficient in computer usage, demonstrate that e-commerce platforms such as Taobao can operate effectively in rural areas. Farmers in Guangxi have employed live streaming platforms like Douyin to improve product visibility and draw in more clients. These examples illustrate that the application of digital technology, coupled with requisite skills, can enhance agricultural development and revenue diversification. In less developed regions like Qinghai and Inner Mongolia, digital penetration is still limited. Despite efforts to advance digital agriculture, infrastructural challenges and a lack of expertise remain prevalent. As of 2020, only 19.4% of agricultural enterprises in Qinghai had adopted digital technologies. A considerable proportion of farmers in these areas lack access to market data, training, and modern tools. These factors impede the improvement of productivity.

This study illustrates that, while digital literacy is crucial, it alone is insufficient. Its effectiveness depends on a comprehensive ecosystem that includes strong infrastructure, localized training, and supportive policies. This evidence underscores the need for customized approaches that address regional disparities, rather than relying on uniform national programs. Future research may focus on evaluating the effectiveness of certain digital teaching methodologies and examining their interaction with local socio-economic variables. It would be beneficial to examine the longitudinal performance of digital literacy initiatives and the factors influencing their sustained effectiveness and impact on rural development. In summary, the findings offer a clearer understanding of the mechanisms of digital knowledge spillovers in practical contexts. This study addresses the digital divide between rural and urban regions and fosters inclusive, sustainable agricultural development by identifying optimal operational times.

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Conflicts of Interest: We declare no conflict of interest.

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