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Digital Economy and Inclusive Development of New Agricultural Operating Entities

Ziming Han | Qiao Liang

China Academy for Rural Development, School of Public Affairs, Zhejiang University, Zhejiang, Hangzhou, People's Republic of China

Correspondence: Qiao Liang (liangqiao2323@126.com)

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ABSTRACT

New agricultural operating entities (NAOEs) are essential agricultural players. With the development of the digital economy in the agricultural sector, both opportunities and challenges may arise for the NAOEs. This study examines the effects of the digital economy on the performance of NAOEs by using a comprehensive dataset containing information on nearly the entire population of family farms, farmer cooperatives and agricultural companies from 2013 to 2020 in China. The mechanisms and inclusiveness of these effects have also been explored. Our results find that the digital economy positively impacts NAOEs' performance in terms of sales revenue and profit. These effects are realised by improving agricultural inputs and market transaction conditions. The effects are more profound for farmer cooperatives, agricultural companies and NAOEs with lower profitability and larger organisation size. The magnitude of the effects is larger for NAOEs located in regions with better topographic, economic conditions and higher digital economy levels. In addition, the synergy between traditional and digital infrastructures can enhance these effects. The conclusion provides insights and guidance for encouraging the high-quality and inclusive development of NAOEs in the digital age.

JEL Classification: L25, O33, Q13

1 | Introduction

Promoting the high-quality development of the agricultural industry is a topic of global concern, and one approach is to enhance the capabilities of agricultural organisations (Grandori 2015; Verhofstadt and Maertens 2015). The new agricultural operating entities (NAOEs) are professional farming entities in the Chinese context (Zheng 2024), including family farms, farmer cooperatives and agricultural companies, which are essential players in agriculture (Huang and Liang 2018). The development of NAOEs is vital not only for boosting the competitiveness of the agricultural industry but also for fostering inclusive growth among local smallholder farmers (Glover and Jones 2019; Liverpool et al. 2023). However, various agricultural organisations in developing countries are currently undergoing transformation and facing challenges related to low-profit margins (Reardon et al. 2009; Schoneveld 2022).

NAOEs in China are no exception, and they also face difficulties in economic performance and sustainable development. Nearly half of the family farms earn < 13,750 USD and primarily focus on crop production (MARA, 2024). A quarter of the top 500 farmer cooperatives in China reported operational revenues below 0.78 million USD, while the average profit margin of the top 500 agricultural companies was just 3.55% in 2021, reflecting declines of 1.10% and 1.19% from 2020 and 2019,

respectively. The average investment in research and development (R&D) and branding by these agricultural companies accounted for only 1.29% and 0.78% of their total operational revenues. Hence, the high-quality development of NAOEs in China requires great attention and support, which would also offer valuable insights for other developing countries.

The rapid development of the digital economy has greatly impacted various market entities, undoubtedly creating new opportunities and challenges for NAOEs. The widespread application of digital technologies like artificial intelligence, blockchain and the Internet of Things has allowed the digital economy to merge with the real economy and quickly extend into agriculture. This evolution not only facilitates communication and trust-building among stakeholders but also helps NAOEs optimise resources such as labour, capital and technology, thus promoting productivity. Furthermore, the digital economy generates new platforms, products and business models, creating a favourable business environment for NAOEs' development. However, there may be a digital divide in the effectiveness of the digital economy due to differences in the individual and regional characteristics of NAOEs, highlighting the need for further empirical evidence on their inclusive development within this context.

Scholars have extensively explored the relationship between digital economy development and organisational performance in recent decades, indicating that the digital economy positively promotes innovation and entrepreneurship (Yunis et al. 2018), enhances human capital (Bloom et al. 2014), increases investment (Islam et al. 2018) and boosts industry clustering (Dong et al. 2021), all of which improve organisational performance. While some studies mention the inclusiveness of agricultural value chains and producer organisations with varying characteristics and external environments (Bijman and Wijers 2019; German et al. 2020; Miller and Mullally 2022), there is a lack of in-depth analysis regarding the digital economy's role in the inclusive development of NAOEs and its diverse impacts. Additionally, the existing literature primarily focuses on industrial or financial companies in developed countries, leaving a gap in evidence regarding the effects of the digital economy on the performance of agricultural organisations.

Hence, this study aims to fill the research gap by exploring the effects of the digital economy on NAOEs' performance in China. The specific research questions are as follows: Does the digital economy level impact the performance of NAOEs? If so, what are the mechanisms of these effects? Are the effects inclusive of the NAOEs with different endowments and features? To answer these questions, we first develop an analytical framework to analyse the mechanisms by which the digital economy affects the performance of NAOEs. We then use a database constructed based on data from multiple sources to empirically investigate the effects of the digital economy on the performance (i.e., sales revenue and profit) of NAOEs.

This study makes three potential contributions. First, it is one of the first studies to examine the effects of regional digital economy development on the performance of various agricultural operating entities in developing countries. Previous studies have primarily looked at the effects of the digital economy on industrial and manufacturing companies (Aral and Weill 2007; Bartel et al. 2007; Bloom et al. 2014), with limited attention given to agricultural organisations. Our results indicate that the level of the digital economy has significantly positive effects on the performance of NAOEs.

Second, this study discusses whether the effects of the digital economy are inclusive for NAOEs with different individual and regional characteristics. The results reveal that the effects of the digital economy are more profound for farmer cooperatives, agricultural companies and NAOEs with lower profitability and larger organisation size. These effects are mainly reflected in regions with better topographic and economic conditions and higher levels of the digital economy, which in turn may lead to larger performance gaps among NAOEs. Additionally, synergy between traditional and digital infrastructure can enhance the positive effects of the digital economy on the performance of NAOEs.

Third, this study constructs an indicator to measure the level of the digital economy and utilises a unique and comprehensive dataset of NAOEs. The digital economy level is indicated by a comprehensive index system that includes four dimensions: digital industry, digital innovation, digital users and digital platforms. A dataset containing business information of nearly the entire population of NAOEs in China is used in the empirical analyses. While most existing studies rely on microlevel data due to the sample specificity and size limitations, this study simultaneously incorporates samples from three types of NAOEs, totalling 1,240,094 NAOEs.

The rest of this paper is organised as follows. Section 2 reviews the literature and analyses the theoretical mechanism of the association between digital economy development and the performance of NAOEs. Section 3 describes the data, model and variables. The empirical results are presented in Section 4. Section 5 is dedicated to further analysis by exploring whether the effects of the digital economy are inclusive of NAOEs. Section 6 provides the conclusions and policy implications.

2 | Literature Review and Theoretical Framework

2.1 | Literature Review

The existing literature on the factors influencing the performance of NAOEs can be categorised into three main aspects. The first is environmental characteristics, such as regional culture, institutions and policy support (Bu and Liao 2022; Deng et al. 2010). For example, Timpanaro and Foti (2024) found that financial support can strengthen the resilience of agri-food enterprises in response to the crises caused by the COVID-19 pandemic and the war in Ukraine. Second, the individual characteristics of NAOEs, such as the type of governance structure and organisation size, are also important influencing factors of NAOEs' performance (Banerjee et al. 2001; Bojnec and Latruffe 2013; Soboh et al. 2012). Liang et al. (2023) noted that membership size has a positive impact on the performance of farmer cooperatives in the early stages, while an inverted U-shaped relationship between membership size and performance is observed as the years of operation of cooperatives increases. The third aspect is management

characteristics, such as the social capital and human capital of managers (Grashuis and Su 2019; Peng et al. 2020; Su and Cook 2020).

Since Tapscott (1996) introduced the concept of 'digital economy', the discussions on digital technologies and their application in various organisations, industries and markets have attracted considerable attention (Chen 2020; Pan et al. 2022; Rumana and Richard 2018). While there is a rich body of research on the impact of the digital economy on business and the digital divide, studies especially examining its impact on the performance of new agricultural operating entities are scarce. Gloy and Akridge (2000) found that farm managers are inclined to use the internet, viewing personal computers as a means to maximise profits. A study based on data collected from 3512 farmer cooperatives in Vietnam reported that internet usage has a positive effect on returns on assets, returns on equity, labour productivity and payments per labourer of agricultural cooperatives (Nguyen et al. 2023).

The results regarding the impact of the digital economy on companies are mixed. Most studies show that the development of the digital economy and the application of digital technologies can refine the precision of production management processes, intellectualise production equipment, improve labour productivity and enhance companies' oversight of cost–benefit dynamics, thus exerting a positive influence on organisational performance (Cuevas-Vargas et al. 2022; DeStefano et al. 2018). Nevertheless, some researchers argue that the digital economy does not necessarily have a positive impact on companies' performance and may even cause a digital divide. For example, Colombo et al. (2013) discovered that the adoption of basic broadband applications by small and medium-sized companies does not necessarily increase productivity and might even have negative consequences.

In summary, the existing literature provides a solid theoretical and empirical basis for our study; however, there are still some research gaps. First, existing studies have mainly focused on the effects of the digital economy on industrial and manufacturing companies, neglecting its impact on various agricultural operating entities, particularly large-scale farming entities. Second, the direct adoption of digital tools by NAOEs remains limited, making it difficult to identify the effects of the digital economy on performance at the individual level. Therefore, it is necessary to explore the effects of the digital economy at the regional level on the performance of NAOEs.

2.2 | Theoretical Framework

2.2.1 | Direct Effects

The digital economy relies on the development of digital technology and must be integrated with various real industries and market entities involved in economic activities (Goldfarb and Tucker 2019). As one of the market entities, the digital economy impacts the development of NAOEs in at least three ways. First, it enhances the productivity of NAOEs. The development of the digital economy makes agricultural production more mechanised, intelligent and precise, for example, by timely monitoring the climate, pests and diseases and soil information of crops, which boosts agricultural production efficiency and improves the performance of agricultural operating entities (Gebbers and Adamchuk 2010; Klerkx et al. 2019).

Second, the digital economy facilitates the internal governance and management of NAOEs. Various information management software is applied in the management of organisations, which strengthens communication and lowers the operational costs of NAOEs.

Third, the development of the digital economy overcomes information asymmetry and helps NAOEs to gain better access to markets. It enables a series of new platforms and business models, such as live streaming, e-commerce and the sharing economy, providing more opportunities for NAOEs and rural households (Couture et al. 2021; Czernich et al. 2011; Leng 2022). According to the China Digital Rural Development Report (2022), online retail sales in rural areas of China reached 0.30 trillion USD, and 36.3% of agricultural leading enterprises engaged in e-commerce sales.

2.2.2 | Mechanisms

The aforementioned analysis indicates that the digital economy may directly impact the performance of NAOEs, but the underlying mechanisms remain unclear. We propose that the digital economy affects the performance of NAOEs in two main ways: improving inputs (e.g., technology and financial capital) and market transaction conditions. First, the development of the digital economy promotes technological innovation, which improves the performance of NAOEs. Data information and knowledge sharing among different market entities have become more frequent in the digital age, which is beneficial for the R&D cooperation of innovative technologies, thereby providing opportunities for NAOEs to adopt new technologies and improve production efficiency (Acemoglu and Restrepo 2018; Wu et al. 2019). Meanwhile, the digital economy speeds up technological innovation and application across different stages of the agricultural sector, such as production, processing and marketing. Technological innovation driven by the digital economy and various digital technologies can lower operational costs and enhance efficiency, thereby fostering the performance of NAOEs (Aral and Weill 2007).

Second, the development of the digital economy facilitates financial accessibility for the agricultural sector and, therefore, enhances the performance of NAOE. Insufficient financial capital is a crucial factor constraining the development of farming entities with limited assets, and the digital economy is conducive to addressing this problem. For one thing, the emergence of digital tools like internet finance, mobile payments and online credit can eliminate information barriers between financial institutions and those seeking credit, making it easier for NAOEs to obtain financial information and services. For another thing, the construction of big data platforms can collect massive amounts of information about credit records and collateral of NAOEs, reducing the verification and tracking costs for financial institutions. Improvements in financial accessibility can help NAOEs increase agricultural investments,

boost business confidence and promote long-term investment, thereby improving their performance.

Third, the development of the digital economy can enhance the performance of NAOEs by improving their business environment. Uncertainties in policy execution and insufficient market information cause frictional costs for businesses. The development of the digital economy increases information disclosure by the government and media, and, therefore, facilitates NAOEs to obtain information at relatively lower costs. At the same time, the digital economy can eliminate geographical barriers, minimise product price disparities and significantly lower various transaction costs for businesses (Goldfarb and Tucker 2019; Parker et al. 2016).

3 | Methodology

3.1 | Data

The data are from multiple sources. First, information regarding all family farms, farmer cooperatives and agricultural companies in China is from the China Academy for Rural Development-Qiyan China Agri-Research Database (CCAD). Each market entity is required to register and submit business information annually through the National Enterprise Credit Information Publicity System (NECIPS), from which the CCAD collects information on the entire population of NAOEs. This ensures the reliability of the data and the representativeness of the sample. The CCAD database contains a rich set of variables related to NAOEs characteristics, financial indicators, shareholders and capital information. Specifically, the business registry data contain the name, location, establishment date, business scope, etc., and the accounting data include information such as sales revenue and profit. The registry and accounting data are matched by a unique ID for each entity. Second, the data for the level of digital economy and eco-social characteristics were obtained from the China Statistical Yearbooks, China's City/County Statistical Yearbooks, the CCAD database and the Peking University Digital Inclusive Finance Index (PUDIFI). According to the data availability, the research period is from 2013 to 2020.

Multiple steps are taken to clean the data. First, we exclude NAOEs with missing sales revenue and profit data or unreasonable information. NAOEs from four directly administrated municipalities (Beijing, Tianjin, Shanghai and Chongqing) are also excluded because the proportion of agricultural output value in these cities is very low. Second, we delete farmer cooperatives with less than five members. According to the *Law of the People's Republic of China on the Specialised Farmer Cooperatives*, farmer cooperatives should have no less than five members. It should be noted that not all NAOEs submitted their annual business information on time to the NECIPS, and some NAOEs chose not to disclose their annual business information to the public. Consequently, the number of NAOE observations for each year used in this study is less than the population of NAOEs, however, a sufficiently large sample size and national representativeness are ensured. Specifically, a database containing 1,240,094 NAOEs from 1776 counties in 247 cities is established. The sample comprises 80,435 family farms, 565,112 farmer cooperatives and 594,547 agricultural companies.

3.2 | Empirical Model

To empirically examine the effects of the digital economy on the performance of NAOEs, the following baseline regression model is established:

$$y_{cit} = \alpha + \beta Dig_{ct-1} + \boldsymbol{\gamma}' \mathbf{X_{cit}} + \lambda_i + \mu_t + \varepsilon_{cit} \quad (1)$$

where y_{cit} denotes the performance of NAOE i in city c in year t, Dig_{ct-1} refers to the digital economy at the city level. Considering that the development of the digital economy may have a lagged effect on NAOEs, we take the digital economy with a lag of 1 year as an independent variable and β captures the effects of the digital economy on NAOEs' performance. $\mathbf{X_{cit}}$ is the vector of control variables, and individual fixed effects and year fixed effects are denoted by λ_i and μ_t, respectively. The error term, ε_{cit}, is clustered at the city level.

Equation (1) may suffer from an endogeneity problem caused by reverse causality because NAOEs with better performance are more likely to be engaged in the digital economy. We use two methods to address endogeneity and estimation bias. First, the staggered difference-in-differences method (DID) is used, and the establishment of the Comprehensive Pilot Zone for Cross-Border E-Commerce (CPZCBE) in China is taken as a quasi-natural experiment to assess the effect of the exogenous policy shock related to the digital economy on NAOEs' performance. CPZCBE started in 2015 and aimed to promote the technical standards and information construction of cross-border e-commerce transactions, payments, logistics and other links (Zhong et al. 2022). In total, 99 cities were approved by the State Council of China to be the CPZCBE in succession by 2020. Therefore, we construct a core independent variable 'policy', which equals 1 when a city became a pilot zone in a certain year and after that year and otherwise equals 0.

Next, we use the instrumental variable method and the spherical distance from the centre of a city to the centre of Hangzhou City, where the headquarters of the Ant Group is located, according to Yang and Zhang (2022). The Alipay of the Ant Group originated in Hangzhou City and has been used by more than 800 million Chinese people for online payment and digital finance. Therefore, it provides a solid foundation for the development of digital economy in China. The closer the city is to Hangzhou City, the higher the level of the digital economy may be. Meanwhile, since geographical distance does not change over time, which ensures exogeneity, we interact it with the logarithm of the national number of internet users in year $t-1$ as the instrumental variable, following the approach of Nunn and Qian (2014).

3.3 | Variable Definitions

3.3.1 | Performance of NAOEs

The dependent variables in this study are the performance of NAOEs, which are measured by the logarithm of sales revenue and profit. The sales revenue reflects the income from the main business of the NAOEs, while the profit is the net amount after

TABLE 1 | Index system for measuring the level of the digital economy.

First-level indicator	Second-level indicators	Third-level indicators	Data sources
Digital economy	*Digital industry*	Proportion of employment in information transmission, computer services and software industry	China City Statistical Yearbooks
		Per capita software business revenue	China Statistical Yearbooks
	Digital innovation	Number of patents authorised for 5G industry	China Academy for Rural Development-Qiyan China Agri-Research Database
		Number of patents authorised for industrial internet	
		Number of patents authorised for e-commerce	
	Digital users	Mobile phone penetration rate	China City Statistical Yearbooks
		Per capita telecommunications business volume	
		Per capita number of internet broadband users	
		Average transaction volume of e-commerce companies	China Statistical Yearbooks
	Digital platforms	Number of domain names	China Statistical Yearbooks
		Number of web pages	
		Digital Inclusive Finance Index	Peking University Digital Inclusive Finance Index

deducting various expenses. We take the logarithm to exclude observations with missing sales revenue and profit values.

3.3.2 | Digital Economy

The digital economy relies on the deep integration of digital technology and the real economy, encompassing digital transformation and innovation across different sectors, active digital platforms and extensive user participation. Therefore, we use a comprehensive indicator system to measure the level of digital economy development by referring to Li et al. (2022) and Pan et al. (2022). Specifically, the system includes four dimensions: digital industry, digital innovation, digital users and digital platforms. The relevant indicators are reported in Table 1, and the entropy weight method is used to calculate the level of the digital economy at the city level.

3.3.3 | Control Variables

The performance of NAOEs is influenced by various factors, so control variables at the individual NAOE, county and city levels are included in the empirical models. Specifically, we use the number of employees or cooperative members and their square terms to examine the inverted U-shaped relationship between organisation size and performance (Liang et al. 2023). We also control for other characteristic variables that may affect the performance of NAOEs, such as operation age and its square term, website status, investment experience, commercial guarantee record and equity change information (Bu and Liao 2022; Ji et al. 2024). Additionally, we control for variables such as the proportion of secondary and tertiary industries, the ratio of government fiscal revenue to expenditure and the ratio of deposit to loan at the regional level.

The detailed definitions and measurements of the variables are presented in Table 2. The index reflects the development level of the digital economy, increasing from 0.018 in 2013 to 0.033 in 2020. At the same time, the average level of the digital economy is 0.025 and the standard deviation is 0.017, reflecting large variances in the digital economy level between cities, ranging from a minimum value of 0.002 to a maximum value of 0.230.

4 | Empirical Results

4.1 | Baseline Results

Table 3 reports the effects of the digital economy on the performance of NAOEs by using Equation (1). As shown in Columns (1) and (2), the digital economy significantly and positively impacts the sales revenue and profit of NAOEs after controlling for individual and year fixed effects. Columns (3) and (4) further control for characteristic variables at the individual level; the regression coefficients for the digital economy, and the results are robust. After controlling for characteristic variables at the region level, the results in Columns (5) and (6) also remain

TABLE 2 | Descriptive statistics of variables.

Variable	Definition	Mean	SD	Min	Max
Dependent variables					
Sales revenue	The logarithm of the sales revenue (10,000 RMB)	3.328	2.140	−9.210	17.584
Profit	The logarithm of the profit (10,000 RMB)	1.848	1.897	−13.816	15.225
Independent variable					
Digital economy	Level of digital economy of the city in year $t-1$	0.025	0.017	0.002	0.230
Control variables					
Size	Number of employees or cooperative members/100	0.181	1.747	0.010	591.780
Age	The operation age of the NAOE	5.285	4.914	1.000	72.000
Web	Is there a website or online store: 1 = yes, 0 = no	0.003	0.053	0.000	1.000
Invest	Is there any external investment or purchase of equity in other companies: 1 = yes, 0 = no	0.002	0.045	0.000	1.000
Extguarantee	Is there any external guarantee information provided: 1 = yes, 0 = no	0.001	0.029	0.000	1.000
Equity	Is there a change in shareholder equity: 1 = yes, 0 = no	0.001	0.034	0.000	1.000
Sec_ind	Proportion of added value of secondary industry to GDP in the county	0.388	0.139	0.014	0.903
Thi_ind	Proportion of added value of tertiary industry to GDP in the county	0.414	0.105	0.065	0.981
Rev_exp	Ratio of general government fiscal revenue to expenditure in the city	0.388	0.208	0.069	1.116
Dop_loan	Ratio of deposits to loans in financial institutions in the city	1.498	0.817	0.161	16.733
Mechanism variables					
Patent applications	Total number of agricultural patent applications in the city/10,000	0.025	0.039	0.000	0.493
Patent authorizations	Total number of agricultural patent authorisations in the city/10,000	0.014	0.022	0.000	0.277
Financial accessibility	Agricultural credit amount in the city (1000 billion RMB)	0.097	0.087	0.004	0.855
Business environment	The logarithm of the commercial credit environment index in the city	4.242	0.045	4.125	4.392

Note: Due to the lack of agricultural credit data at the city level, we collect the agricultural credit amounts of each province and then multiply it by a ratio at the city level to measure the agricultural financial accessibility at the city level. The ratio is calculated by dividing the number of agricultural financial institutions in the city by the number of agricultural financial institutions in this province. The commercial credit environment index was published in 2010, 2011, 2012, 2015, 2017 and 2019, and we use linear interpolation to fill in the index for the remaining years for each city.

consistent. Specifically, the regression coefficients for the digital economy are positive and significant at the 1% level; for every 0.01 increase in the digital economy level, the sales revenue and profit of NAOEs increase by 2.816% and 3.582%, respectively. Our results indicate that the digital economy plays an important role in improving the performance of NAOEs, aligning with the studies by Gloy and Akridge (2000), Jabbouri et al. (2023) and Nguyen et al. (2023).

The regression coefficients for control variables in Columns (5) and (6) of Table 3 reveal that the size of NAOEs has a significantly positive impact on performance, while the square term of the size has a significantly negative impact on performance, indicating an inverted U-shaped relationship between NAOEs' size and performance. The operation age and its square term both negatively impact the performance of NAOEs. Despite the rapid development of online platforms in recent years, the proportion of NAOEs using websites and online stores remains low, resulting in insignificant impacts on the performance of NAOEs.

We further explore the effects of each of the four dimensions of the digital economy on the performance of NAOEs. The results show that the development of the digital industry, digital innovation and digital platforms significantly improve the business performance of NAOEs. The effects of digital users on the performance of NAOEs are negative but not significant. This may be because of the relatively small variance in the variable digital users over the years and among regions. The details of these results are presented in Table S1 in Appendix S1.

TABLE 3 | Effects of digital economy on the performance of NAOEs.

	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit
	(1)	(2)	(3)	(4)	(5)	(6)
Digital economy	2.409***	3.576***	2.560***	3.494***	2.816***	3.582***
	(0.790)	(0.900)	(0.906)	(0.940)	(0.843)	(0.915)
Size			0.073***	0.060***	0.073***	0.060***
			(0.012)	(0.011)	(0.012)	(0.011)
Size_sq			−0.000***	−0.000***	−0.000***	−0.000***
			(0.000)	(0.000)	(0.000)	(0.000)
Age			−0.043***	−0.036***	−0.040***	−0.035***
			(0.009)	(0.008)	(0.010)	(0.009)
Age_sq			−0.002***	−0.000	−0.002***	−0.000
			(0.001)	(0.000)	(0.001)	(0.000)
Web			0.080	0.052	0.081	0.052
			(0.057)	(0.069)	(0.057)	(0.069)
Invest			0.023	−0.000	0.026	0.001
			(0.061)	(0.089)	(0.061)	(0.089)
Extguarantee			0.002	0.080	0.003	0.080
			(0.091)	(0.095)	(0.091)	(0.095)
Equity			0.121*	0.058	0.120*	0.058
			(0.070)	(0.091)	(0.070)	(0.091)
Sec_ind					0.076	0.036
					(0.295)	(0.358)
Thi_ind					−0.317	−0.098
					(0.335)	(0.392)
Rev_exp					−0.304**	−0.092
					(0.145)	(0.165)
Dep_loan					−0.008***	−0.003
					(0.001)	(0.002)
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.561***	1.930***	3.595***	1.964***	3.807***	2.023***
	(0.023)	(0.029)	(0.037)	(0.036)	(0.263)	(0.319)
Observations	1,215,227	971,594	1,110,888	889,553	1,110,888	889,553
R^2	0.008	0.004	0.009	0.004	0.009	0.004

Note: Size_sq and *Age_sq* are the square terms of *Size* and *Age*, respectively. Standard errors clustered at the city level are shown in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

4.2 | Endogeneity Analysis and Robustness Checks

4.2.1 | Staggered Difference-in-Differences Method

The staggered DID method is used to examine the effects of the digital economy on the performance of NAOEs by taking the CPZCBE policy as a quasi-natural experiment. The regression coefficients in Columns (1) and (2) of Table S2 indicate that the establishment of the CPZCBE is associated with a 9.50% increase in sales revenue and an 8.00% increase in the profit of NAOEs, respectively. After controlling for various variables and fixed effects, the regression coefficients in Columns (3) and

(4) remain robust, revealing the positive roles played by the digital economy.

The results in Figure S1a,b in Appendix S1 further show that the regression coefficients for each period before the implementation of the CPZCBE policy are mostly insignificant, but are all statistically significant after the policy implementation. This means that the parallel trends assumption is satisfied because the key assumption of the DID model is that the treatment and control groups should have no significant trend differences before the external shock occurs. Placebo tests are also conducted by randomly selecting 99 cities as the treatment group and assigning a year from the research period as the policy implementation time for these cities. The effects of policy implementation on the performance of the NAOEs are then estimated and repeated 500 times. The results are shown in Figure S1c,d. The regression coefficients for the policy are normally distributed around zero, with the majority not passing the 10% significance test. This again confirms the robustness of the estimation results.

4.2.2 | Instrumental Variable Method

The instrumental variable estimation results are shown in Table S3 in Appendix S1. The Kleibergen-Paap rk LM statistics pass the significance test at the 1% level, and the Cragg–Donald Wald F statistics exceed the critical values of the Stock Yogo weak-identification test at the 10% level, indicating that the instrumental variable is effective. The results in Columns (1) and (3) indicate that the closer the spherical distance from a city to Hangzhou, the higher is the level of the digital economy. The results in Columns (2) and (4) show that the digital economy significantly increases the sales revenue and profit of NAOEs. Compared with the results in Columns (5) and(6) of Table S3, the effects estimated in the baseline results may be underestimated.

4.2.3 | Change of Sample Scope

Some observations are removed from the sample to avoid potential errors. First, we exclude agricultural companies and family farms with fewer than five employees, as the operational capacity of these small farming entities is generally weak. We then remove NAOEs from three provinces (Hainan, Xizang and Xinjiang) because of the limited number of NAOEs in these areas. The results in Columns (1) and (2) of Table S4 in Appendix S1 show that digital economy development significantly increases the sales revenue and profit of NAOEs at the 1% significance level, which confirms the baseline results. Next, we exclude farmer cooperatives with exactly five members because some cooperatives may intentionally gather five members to meet the registration requirement in order to grasp governmental subsidies. As shown in Columns (3) and (4) of Table S4, the results remain robust.

4.2.4 | Alternative Dependent Variables

The dependent variables are replaced by sales revenue and profit per capita, which are calculated by the sales revenue and profit of NAOEs by the number of members or employees. The regression coefficients are 2.378 and 2.919, respectively, as shown in Columns (5) and (6) of Table S4, indicating that the digital economy positively increases the sales revenue and profit per capita of NAOEs.

4.3 | Mechanisms of the Effects

The baseline regression results and robustness checks confirm the positive effects of the digital economy on the performance of NAOEs. In this section, we further examine whether the digital economy can impact NAOEs' performance through facilitating technological innovation and financial accessibility and improving the business environment.

Advancements in technological innovation enable NAOEs to boost productivity, which in turn enhances their performance. Agricultural technological innovation is measured by two indicators: the total number of agricultural patent applications and authorisations at the city level. The results in Columns (1) and (2) of Table 4 indicate that digital economy development leads to an increase in both the number of agricultural patent applications and authorisations; the regression coefficients are 0.970 and 0.593, respectively.

Financial capital is an essential input factor for the NAOEs. The increase in financial accessibility helps NAOEs resist natural risks, expand their business scope and upgrade their industrial chains, thereby improving NAOEs' business performance. Due to the lack of data on agricultural loans at the city level, financial accessibility is measured by agricultural loans at the provincial level multiplied by the ratio of the number of agricultural financial institutions in that city to that in the province. As Column (3) of Table 4 shows, the digital economy significantly increases the accessibility of agricultural finance at the 1% significance level.

As market participants, the performance of NAOEs can also be affected by the business environment and market transaction costs. The Commercial Credit Environment Index at the city level serves as a measure of the market environment. The Index is reflected by three dimensions: corporate credit management, government credit supervision and the completeness of the credit market. The results are shown in Column (4) of Table 4, indicating that the digital economy has positively improved the market environment.

5 | Are the Effects of the Digital Economy Inclusive?

These findings suggest that the digital economy can enhance the performance of NAOEs. However, whether the effects of the digital economy are inclusive for NAOEs with different characteristics still needs further discussion (Lythreatis et al. 2022). First, the three types of entities—family farms, cooperatives and agricultural companies—have different organisational attributes and fulfil different roles in the supply chains. Family farms primarily focus on agricultural production, while farmer cooperatives and agricultural companies are more involved in

TABLE 4 | Mechanisms of the effects of the digital economy.

	Patent applications	Patent authorisations	Financial accessibility	Business environment
	(1)	(2)	(3)	(4)
Digital economy	0.970***	0.593***	0.714***	0.528***
	(0.343)	(0.171)	(0.244)	(0.101)
Control variables	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Constant	0.029	−0.008	−0.079***	4.217***
	(0.020)	(0.013)	(0.027)	(0.057)
Observations	1920	1917	1943	1900
R^2	0.353	0.416	0.594	0.349

Note: The individual-level control variables are excluded in Columns (1) to (4), *Sec_ind* and *Thi_ind* are replaced at the city level and the other two control variables in the columns are the same as those in the baseline model. Standard errors clustered at the city level are shown in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

value addition and market activities. As a result, the influence of the digital economy may differ among these entities. Second, NAOEs with different levels of profitability and size may differ in their adoption levels of digitalisation, which in turn results in heterogeneous effects of the digital economy on their performance. Third, the effects of the digital economy on NAOEs are contingent upon regional factors, including topographic conditions, economic development, the levels of the digital economy and infrastructure availability in different areas. These environmental characteristics can lead to heterogeneous effects of the digital economy on NAOEs' performance. Therefore, this section examines the heterogeneity of effects across NAOEs with different individual and regional characteristics.

5.1 | Heterogeneity Across Organisational Types

The effects of the digital economy on the performance of each type of NAOEs are estimated, and the results in Table 5 show that the effects are heterogeneous. Specifically, the development of the digital economy significantly increases the sales revenue and profit of farmer cooperatives and agricultural companies, as shown in Columns (3–6) in Table 5. Comparatively, the level of the digital economy does not exhibit a significant influence on the performance of family farms, as shown in Columns (1) and (2). A possible explanation is that the digital economy has already penetrated the agricultural management and markets, thereby impacting performance of cooperatives and agricultural companies, as they have more market shares and sales businesses. However, the application of digital technologies in the agricultural production process is limited, resulting in an insignificant influence on the performance of family farms.

5.2 | Heterogeneity Across NAOEs With Different Profitability and Size

To analyse the heterogeneous effects of the digital economy on the performance of NAOEs with different levels of profitability, we calculate the average profit margin of each NAOE during the research period and divide the sample into two groups based on the median value. The profit margin is calculated by dividing the profit by sales revenue. The results shown in Columns (1–4) of Table 6 reflect that digital economy development significantly improves the performance of NAOEs with lower profit margins, indicating that the development of the digital economy offers more opportunities for NAOEs with low profitability to achieve revenue and profit improvement.

We further verify whether the effects of the digital economy on performance depend on organisation size. The sample is also broken down into two groups based on the median value of NAOEs' average size. The regression results in Columns (5–8) of Table 6 reveal that the digital economy significantly increases the revenue and profit for relatively large NAOEs, while improving the profit at the 10% significance level and has no impact on the sales revenue of small NAOEs. The possible reasons are that NAOEs with larger sizes often have better business capabilities and social capital, which facilitates better access to digital technology and the application of various digital platforms than their counterparts.

5.3 | Heterogeneity Across Regional Characteristics

We first examine whether the digital economy promotes inclusive development of NAOEs in regions endowed with different topographic and economic conditions. Columns (1–4) of Table 7 show the effects of the digital economy on the performance of NAOEs in the plain and non-plain regions. It can be observed that the digital economy promotes the sales revenue and profit of NAOEs in both plain and non-plain regions. Fisher's permutation test is used to check for statistically significant differences between the coefficients of the two groups. The results demonstrate significant differences in the effects between plain and non-plain regions, indicating that the coefficients of the effects of NAOEs in plain regions are larger than those in non-plain areas.

TABLE 5 | Heterogeneity across organisational types.

	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit
	Family farms		Farmer cooperatives		Agricultural companies	
	(1)	(2)	(3)	(4)	(5)	(6)
Digital economy	1.454	2.312	3.531***	3.468***	2.002**	3.407**
	(3.153)	(3.284)	(1.228)	(0.955)	(0.957)	(1.345)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	2.953***	2.291***	3.908***	2.210***	3.917***	1.892***
	(0.492)	(0.549)	(0.373)	(0.480)	(0.229)	(0.230)
Observations	77,216	72,681	493,573	414,609	540,099	402,263
R^2	0.014	0.013	0.015	0.009	0.007	0.002

Note: Standard errors clustered at the city level are shown in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

TABLE 6 | Heterogeneity across NAOE characteristics: Profitability and size.

	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit
	High profitability		Low profitability		Large size		Small size	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digital economy	2.017	2.731*	3.326***	4.131***	3.465***	3.332***	1.333	3.503*
	(1.666)	(1.465)	(0.658)	(0.823)	(0.796)	(0.755)	(1.545)	(1.905)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.219***	2.258***	4.222***	1.418***	4.196***	2.283***	2.531***	1.103***
	(0.403)	(0.415)	(0.162)	(0.258)	(0.308)	(0.381)	(0.310)	(0.309)
Observations	514,311	502,575	512,626	346,059	754,293	614,850	356,595	274,703
R^2	0.011	0.006	0.010	0.004	0.012	0.005	0.017	0.014

Note: The regression coefficient of the digital economy in Column (8) is slightly higher than that in Column (6), but the *p* value of Fisher's permutation test is 0.181, suggesting no significant difference in the impact of the digital economy on the profits of NAOEs between the large-size and small-size groups. The *p* value of Fisher's permutation test is calculated by sampling 1000 times. Standard errors clustered at the city level are shown in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

Next, we divided the sample into two groups based on the median value of per capita GDP at the county level. The results in Columns (5–8) of Table 7 show that the digital economy positively influences the sales revenue and profit of NAOEs located in countries with higher per capita GDP (*high per capita gdp* group), but has no significant effect on the NAOEs in the *low per capita gdp* group.

The heterogeneity of the effects across regions with different levels of digital economy is also tested. We calculated the average digital economy level of each city from 2013 to 2020 and defined the cities as the *high digital economy* group and *low digital economy* group based on the median value. The results in Columns (9–12) of Table 7 show that the digital economy significantly increases the sales revenue and profits of NAOEs for the *high digital economy* group but has no significant effect for the *low digital economy* group.

Infrastructure is also important for facilitating the function of the digital economy. Therefore, we examine whether the impact of the digital economy on the performance of NAOEs is heterogeneous across regions with different levels of digital and traditional infrastructure. Digital infrastructure (*broadband*) is measured by whether a city participates in the Broadband China programme, which selected 41, 39 and 39 pilot cities in 2014, 2015 and 2016, respectively, to improve local information infrastructure conditions. After a city was selected as a pilot city of Broadband China, *broadband* equals 1. Traditional infrastructure (*hsr*) is measured based on whether a city has high-speed

TABLE 7 | Heterogeneity across regional characteristics.

	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit
	Plain regions		**Non-plain regions**		**High per capita gdp**		**Low per capita gdp**		**High digital economy**		**Low digital economy**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
Digital economy	5.567***	6.086***	2.053**	2.844***	3.014***	3.892***	−1.842	−1.520	2.328***	2.633**	−4.168	−2.767
	(1.209)	(1.438)	(0.947)	(0.825)	(0.664)	(0.864)	(2.332)	(2.126)	(0.685)	(1.003)	(2.952)	(3.007)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.881***	2.126***	3.620***	1.950***	3.707***	1.995***	3.646***	1.844***	3.720***	2.318***	3.551***	1.870***
	(0.342)	(0.334)	(0.315)	(0.502)	(0.336)	(0.542)	(0.362)	(0.327)	(0.429)	(0.726)	(0.305)	(0.246)
Observations	370,315	310,331	688,654	541,909	552,187	420,970	555,986	466,802	568,257	465,338	542,631	424,215
R^2	0.015	0.005	0.007	0.005	0.009	0.004	0.011	0.006	0.008	0.004	0.011	0.007

Note: Standard errors clustered at the city level are shown in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

rail stations, as transportation conditions are very important in traditional infrastructure. After the first high-speed railway station in the city is put into operation, *hsr* equals 1.

The results in Columns (1–4) of Table 8 show that *broadband* or *hsr* does not separately promote the effects of the digital economy on the performance of NAOEs, while the two types of infrastructure display synergistic effects. The interaction term of the digital economy and the two infrastructures, reported in Columns (5) and (6), indicate that for every 0.01 increase in the digital economy level, the synergy of the two types of infrastructure increases the positive effects of the digital economy on NAOEs' revenues and profits by 3.874% and 4.336%, respectively.

6 | Conclusion and Policy Implications

New agricultural operating entities are crucial in linking smallholder farmers with modern agriculture. With the continuous penetration of the digital economy into the agricultural sector, NAOEs encounter both new opportunities and challenges for high-quality development. This study empirically examines the effects of the digital economy on the performance of NAOEs by using a large sample of NAOEs in China. Further discussions on the mechanisms and inclusiveness of these effects are also conducted. The results may have implications for other developing countries where NAOEs are undergoing a transition in the digital economy age.

The main findings are as follows. First, the development of the digital economy positively impacts NAOEs' performance in China, particularly in terms of sales revenue and profit. Second, the digital economy increases NAOEs' performance by increasing the accessibility of agricultural technological innovation and financial accessibility and improving market transaction conditions. Third, the effects of the digital economy are more pronounced for farmer cooperatives and agricultural companies, especially NAOEs with lower profitability, larger sizes and located in regions with favourable topographic and economic conditions, as well as higher levels of digital economy development. Meanwhile, the synergy between traditional and digital infrastructure can enhance the effects of the digital economy on the performance of NAOEs.

Based on these empirical results and discussions, the following policy implications are proposed. First, it is essential to enhance both information and traditional infrastructure to facilitate the digital transformation of agricultural entities, as the empirical results suggest the important role of the digital economy in improving the performance of NAOEs. Therefore, the government should increase investment in the R&D of digital technologies and continue to improve infrastructure conditions in rural areas. Furthermore, it is crucial to encourage partnerships with the private sector to foster digital investments and applications in rural and remote regions, with particular attention to enhancing information infrastructure in non-plain areas and remote mountainous regions.

Second, inclusive digital strategies must be adopted to address the potential digital divide in agriculture. Considering

TABLE 8 | Results of infrastructure development.

	Sales revenue	Profit	Sales revenue	Profit	Sales revenue	Profit
	(1)	(2)	(3)	(4)	(5)	(6)
Digital economy	1.675	2.534**	2.419**	2.534**	2.193	2.449*
	(1.636)	(1.208)	(1.138)	(1.147)	(1.909)	(1.314)
Digital economy×hsr	1.236	1.160			0.101	−0.074
	(1.445)	(0.977)			(1.748)	(1.086)
Digital economy×broadband			0.444	1.333	−3.270	−2.753**
			(0.740)	(0.883)	(2.056)	(1.318)
Digital economy×hsr×broadband					3.874*	4.336***
					(2.012)	(1.260)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.832***	2.044***	3.809***	2.026***	3.803***	2.013***
	(0.265)	(0.318)	(0.263)	(0.317)	(0.261)	(0.316)
Observations	1,110,888	889,553	1,110,888	889,553	1,110,888	889,553
R^2	0.009	0.004	0.009	0.004	0.009	0.005

Note: Standard errors clustered at the city level are shown in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

the heterogeneous impacts of the digital economy on different organisational types, differentiated policy support is essential. Support can specifically target digital applications in agricultural production for family farms and in managerial and marketing practices for farmer cooperatives and agricultural companies. Additionally, it is important that authorities offer necessary support for relatively vulnerable NAOEs, such as providing more financial support and talent training opportunities for smaller NAOEs with lower market powers.

Third, from the perspective of individual NAOE, suitable and customised digital technologies and applications should be actively adopted to respond to the rapid development of the digital economy. Collaborations between NAOEs and technology providers can be achieved through public–private partnerships to facilitate the transfer of digital knowledge and skills. In addition, disadvantaged NAOEs that struggle with digital transformation should carefully consider the cost of participating in the digital economy, and then choose whether to purchase digital services from professional digital service providers or engage in digital innovation on their own.

There are several possibilities for future research. First, the impact of the digital economy on different types of agricultural operating entities can be further explored. Discussions on the heterogeneity and mechanisms of the effects on different types of organisations are limited in the current study due to limited space. Second, it would be beneficial to measure the digital economy at the organisational level, as we believe that the organisational features and participation levels of the digital economy generate different and nonlinear effects. Third, it would be valuable to explore how the digital economy influences different facets of agricultural organisations, such as the resilience of the organisations, and coordination with upstream smallholder farmers and downstream market entities.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Part of the data are available, while the other part of the data that support the findings will be available in China Agri-research Database (CCAD) at https://r.qiyandata.com/welcome following an embargo from the date of publication to allow for commercialization of research findings.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.