Time Evolution and Impact Analysis of Ukraine's Digital Economic Development on Food Security Capacity

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Abstract: The availability of food resources plays a key role in maintaining food safety for consumers. Ensuring the safety and quality of these food resources is essential to preventing food security problems. Currently, however, global food security is severely jeopardised by external factors such as pandemics and wars that hinder the production and distribution of food. Therefore, the development of digital technologies is of strategic importance for food security as their integration with agriculture is emerging as an important tool for maintaining food security. In this study, food security data of Ukraine from 2011 to 2022 were utilised. The importance of digital technologies for safeguarding food security is revealed through time series and random forest models. In addition, this paper observes the negative impact of war on food security.The findings suggest that advances in digital technologies drive efficiency and transparency in the food supply chain, increase the yield and quality of food products, and optimise the synchronisation of supply and demand. In order to further realise the potential of digital technologies in improving food security, this paper makes a number of recommendations. Firstly, it is crucial to emphasise the development of technological innovation and digital infrastructure, especially in the agricultural sector. Second, advocate the widespread adoption of digital technologies in all aspects of food production and distribution to improve the efficiency and sustainability of the food supply chain. In addition, it is crucial to promote synergistic growth between the digital economy and agriculture, empowering farmers to cope with market dynamics through the dissemination and training of digital technologies in order to increase agricultural output and incomes. Nurturing the continued development of digital technologies and enhancing their adaptation in agriculture will maximize their strategic role in ensuring food safety.

Keywords: digital technology , food security , incident of conflict random , forest model time series

1 Introduction

The evolution of the global food security pathway has been divided into three main stages, with the first focusing on quantitative security, the second on both quantitative and nutritional security, and the third on a combination of quantitative security. Food security has always been the cornerstone of economic and social development, and the ability to ensure food security has become a fundamental pillar of the modern economic syste[1] (Moore,1993). With the development of the times, the double pressure of population growth and people's pursuit of high quality life, as well as facing climate risk, trade risk, industry chain security risk, due to

BDEDM 2024, January 12-14, Ningbo, People's Republic of China

DOI 10.4108/eai.12-1-2024.2347154

epidemics and Israel-Palestine conflict, Russia-Ukraine war and other external factors, global agricultural production and food distribution distribution problems. Therefore, not only pay attention to food production, but also pay attention to the development of food quality, in order to achieve high quality, high level of food security[2] (McAfee,2012).

Countries around the world have always attached great importance to food security issues, the Communist Party of China's General Secretary Xi Jinping pointed out in the report of the twentieth Party Congress, all-round consolidation of the foundation of food security, and firmly guard the red line of 1.8 billion mu of arable land, to ensure that the Chinese people's rice bowls firmly in their own hands, the United Nations in recent years, and gradually introduced policies to ensure global food security. Ukraine as the "global breadbasket" although the land area of only 600,000 square kilometres, but the proportion of black soil accounted for 40% of the world, the monthly export of food supplies reached five million tons. Although the value of global food production has been increasing year by year in recent years, it still has to take into account the complex international situation, wars and conflicts, natural disasters, increased public demand and environmental pollution.

Digital technology has gradually become a strategic choice to promote the development of high-level food security[3] (Ghasemaghaei,2019). The modernisation of food security must move from a narrow to a broader sense, with a meaning that is historical and dynamic and centred on the theme of high-level development. Breakthroughs must be made in ways to improve food security capabilities, especially as digital technologies rapidly penetrate the agricultural and rural sectors.The transformative nature of digital technology has facilitated the sharing of agricultural production information, the integration of resources and the interconnection of factors[4] (Konstantinos,2018).This, in turn, has promoted the development of industrial integration and the overall upgrading of the agricultural industry. With the further development of digital technology, it is widely used in agriculture, in addition to the continuous integration of digital technology with agricultural technology and core elements such as information[5] (White,2018).Bringing a profound transformation to agricultural development, digital technology can be seamlessly combined with rural governance mechanisms to catalyse the development of digital villages, which has become a strategic choice for promoting rural revitalisation and agricultural modernisation. Under the constraints of limited resources, digital technology provides an effective way to go beyond resources and the environment. In China's 14th Five-Year Plan, the implementation of a food security strategy was included for the first time in a five-year plan, reflecting the great importance that countries around the world attach to food security, which is a major concern for people's livelihoods. Therefore, the ability of digital technology to empower food security in the context of the new era is of great practical significance to the modernisation of agriculture and rural areas and the revitalisation of agriculture.

2 Literature Review

The rapid evolution of digital technology has opened up new vistas for the advancement of traditional agriculture. Substantial research has widely recognized the practical significance of amalgamating the digital economy with agriculture. Digital technology has the potential to revolutionize agricultural production and management methods, thereby improving efficiency and economic returns [6] (Sinha,2019). The precise control made possible by digital technology, when fully leveraged in modern agricultural development, can ameliorate the impact of resource constraints on agricultural growth, ultimately enhancing overall agricultural productivity. As emphasized [7], the adoption of Internet of Things (IoT) systems brings about innovative transformations in traditional agricultural management, giving rise to new management paradigms centered around agricultural digitization processes and systems. Its potential in meeting human needs should not be underestimated.

Furthermore, with the widespread application of big data, the digital economy is poised to reshape traditional agricultural business models, propelling agriculture towards significant advancements. Iaksch Shepherd, M.et al. (2021) point out that agricultural platforms and application systems built on big data have introduced novel business models rooted in information sharing [21]. These models not only assist farmers in optimizing operational decisions but also enhance their profitability. Moreover, the digital economy is expected to lead the restructuring of the agricultural industry chain, optimizing its layout and expediting the convergence of agriculture with other sectors.

Nonetheless, the integration of digital technology and agriculture also presents a series of risks and challenges that could impact the actual outcomes of their convergence. According to the Law of Disruption, digital technology experiences exponential growth, while changes in economic, societal, and legal systems progress incrementally, leading to potential conflicts between the two. Deichmann et al. (2016) propose that in many developing countries, an excessive emphasis on the openness and adaptability of digital technology could divert attention from the actual beneficiaries within the agricultural industry chain and the potential agricultural comparative advantages based on resource distribution [22]. Additionally, despite being perceived as highly inclusive, digital divides persist along various dimensions, weakening the resources and opportunities available to vulnerable groups and exacerbating issues of uneven development [7] (Harris,2012). Mehrabi et al. found that approximately 80% of agricultural operators with land holdings exceeding 200 hectares are able to effectively integrate digital technology, compared to around 30% for those with land holdings less than [8]. Furthermore, regions with adverse natural conditions and low-yield plots face challenges in harnessing the benefits of digital technology. Shepherd et al. emphasize the imperative of promoting the effective integration of existing digital technologies, providing agricultural producers with more coordinated and consistent digital integration solutions. Agriculture is undergoing profound transformations due to digital reform and information technology; these advancements are poised to enhance the high-quality development and sustainable growth of the agricultural sector [8].

3 Theoretical hypotheses and study design

3.1 Theoretical hypothesis

The impact of digital technology on food security primarily manifests through three dimensions: the production system, operational framework, and industrial structure [9] (Kamilaris,2017). The essence of digital technology lies in its informatization, characterized by high permeability, extensive dissemination, and cost reduction attributes [13] (Janc,2019). Its influence on food security encompasses augmenting arable land protection capability, stimulating market vitality, and balancing efficiency and equity advantages [12] (Schor,2017). Simultaneously, the defining features of digital technology not only have a direct impact on food security capacity but also indirectly enhance it through technological innovation effects and economies of scale.

(1)In the aspect of the production system, the application and promotion of digital technology strengthen the control over land use and the proper use of farmland, thereby providing land protection for food security [14]. Digital technology, encompassing systems such as blockchain, big data, and the Internet of Things (IoT) (Eastwood,2019), represents a new technological paradigm [15]. Its application and promotion on farmland are an emerging trend in agricultural development, with digitized land management being a crucial facet of rural digitalization. Moreover, concerning the enhancement of land productivity through digital technology, it enables efficient, real-time, and precise analysis of the "health" status of land [16]. This provides valuable information for food production, monitoring land quality, and assessing pollution risks, consequently bolstering food security capacity in the pre-production phase [17](Ingram,2109）. Based on these insights, this paper presents the following theoretical hypotheses.

Hypothesis1: Digital technology can enhance food security capacity by influencing the production system.

(2)In the operational framework, digital technology propels the development of smart agriculture and precision farming, leading to finer management within crop fields. This not only enhances crop production efficiency but also reduces costs and increases crop profitability, thereby promoting moderate-scale farming and fostering positive attitudes toward crop cultivation. Concerning the benefits brought by digital technology in crop cultivation, its evolution has led to increased transparency and intensified competitive pressures within the food industry, prompting the agricultural sector to optimize and upgrade its products through increased innovation investments.

Moreover, following the "trickle-down effect," regions or industries that advance first can benefit less-developed areas or industries by means of employment transfer and technological spillovers, ultimately contributing to the growth of these underdeveloped sectors [18]（Stalebrink,2004）. Therefore, leveraging its characteristics of high permeability and extensive dissemination, digital technology might enhance crop profitability in advanced regions. Based on these attributes, advanced regions' technological systems and best practices could be transferred to areas with poorer crop yields, resulting in a positive "spatial overflow" effect. Thus, this paper puts forth the following theoretical hypotheses.

Hypothesis2: Digital technology can enhance food security capacity by influencing the operational framework.

(3)In the industrial structure domain, the application of digital marketing technology and the resulting development of contract farming and customized agriculture effectively align supply and demand information in the production and sales chain, thereby smoothing the grain and oil distribution channels.（Sawant,2016) This is conducive to integrating the entire grain and oil industry chain, connecting grain-producing regions with consumer markets [19]. For example, digital technology can aggregate fragmented grain markets through online platforms, breaking down temporal and spatial barriers to create larger virtual markets on the web, and securing a larger market share compared to traditional markets [20] (Newton,2020). Furthermore, digital technology can stimulate market vitality and optimize supply-demand dynamics [21] (Iaksch,2021).The most direct effect of digital technology is its ability to optimize both sides of the grain market by better addressing user demands for fast and decentralized technological solutions [22](Deichmann,2016). This characteristic can enhance the efficiency of the supply and demand sides of the grain market and further facilitate connectivity between grain-producing and consumer markets. Therefore, this paper introduces the following theoretical hypotheses.

Hypothesis3: Digital technology can enhance food security capacity by influencing the industrial structure.

3.2 Variable selection and data preprocessing

The dependent variable in this study is food security capacity, which is quantified based on four dimensions: the supply-side production dimension, the accessibility dimension, the stability dimension, and the sustainability dimension, all of which are summarized in Table 1.The supply-side production dimension is measured using indicators such as yield per unit area, proportion of cultivated land area, rate of financial support for agriculture, and mechanized power per unit area. The accessibility dimension is characterized by indicators such as food possession per capita and road density. The stability dimension characterizes the stability of food security through the coefficient of fluctuation of total food production. The sustainability dimension is characterized by indicators such as fertilizer application intensity to reflect the sustainability of food production. Finally, the entropy method was used to calculate the food security index.

Table 1. Distribution of weights for food security indicators.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Indicator Explanation	Attribute	Weight
Food Security Capability	Supply-Side Production Dimension	Food Production Capacity	Yield per Unit Area	+	0.0594
		Food Production Security Capability	Proportion of Cultivated Land Area in Common Use	+	0.0538
			Proportion of Agricultural, Forestry, and Water Affairs Expenditure in General Fiscal Expenditure	+	0.0594
			Mechanical Power per Unit Area	+	0.178
	Acquisition Dimension	Degree of Food Satisfaction	Per Capita Food Possession	+	0.054
		Level of Balanced Food Supply	Degree of Road Density	+	0.029
	Stability Dimension	Food Security Stability	Coefficient of Fluctuation in Total Food Production	-	0.01
	Sustainability Dimension	Level of Food Production Sustainability	Intensity of Fertilizer Use	-	0.023

The explanation of variables in this study is displayed in Table 2: The explanatory variables in this study are mainly the level of digital technology development. Three indicators are selected from the digital economy base: the proportion of employees in computer services and software, the ratio of financial expenditure on education to total financial expenditure, and the total amount of telecommunication services. Two indicators are selected to represent the level of digital application: the number of cell phone users per 100 people and the number of Internet users per 100 people. Two indicators are selected to reflect the digital innovation capacity: the proportion of fiscal expenditure on science and technology to total fiscal expenditure and the number of digital economy-related patents per 10,000 people. The entropy method was used to assign weights to each of the above indicators to arrive at the final results of the comparison of the level of digital technological development in Ukraine and China.

Table 2. Distribution of weights for various digital technology indicators.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Indicator Explanation	Attribute	Weight
Digital Numeracy	Foundations of Digital Technology	Digital Industry Development	Proportion of Computer Services and Software Professionals	+	0.063
		Digital Talent Proficiency	Proportion of Educational Financial Expenditure to Total Financial Expenditure	+	0.012
		Telecommunication Service Volume	Per Capita Total Telecommunication Services	+	0.146
	Level of Digital Application	Mobile Phone Ownership	Number of Mobile Phone Users per One Hundred People	+	0.066
		Internet Penetration Rate	Number of Internet Users per One Hundred People	+	0.122
	Digital Innovation Capability	Support for Digital Innovation Elements	Proportion of Scientific Financial Expenditure to Total Financial Expenditure	+	0.169
		Level of Digital Innovation Output	Number of Digital Technology-Related Patents per Ten Thousand People	+	0.485

This study explores the impact of digital technologies on food security using panel data for Ukraine from 2011 to 2022 as the research dataset. Indicator data were mainly obtained from the World Bank database and missing values were estimated using linear interpolation. To ensure smoothness of the variables, all variables in this study were log-transformed. Table 3 presents the descriptive statistics.

Tab 3 presents the descriptive statistics.

variable	Sample size	average value	standard deviation	minimum	maximum
Digital technology	270	0.045	0.023	0.01	0.136
Food security capacity	270	0.038	0.014	0.01	0.133

4 Research Methods and Time Selection

In this paper, a time series model was chosen to analyze the temporal evolution of food security capacity in Ukraine as well as a random forest model to analyze the impact of the development of the digital economy on food security capacity in Ukraine. Time series modelingARIMA model is an important research method for trend forecasting by researchers at home and abroad. ARIMA model can deal with non-stationary time series data through differentiation, and is suitable for forecasting in the field of medicine, GDP forecasting, demographic forecasting, cost forecasting and so on.The ARIMA model, which stands for AutoRegressive IntegThe ARIMA model, which stands for AutoRegressive Integrated Moving Average model, is a time series forecasting model. The steps to build an ARIMA model are as follows:

(1)Stationarity identification: Determine if the time series is stationary or not. If it is not stationary, then differencing needs to be applied until the series becomes stationary.

(2)Parameter selection: Based on the processed autocorrelation and partial correlation plots, estimate the values of p, d, and q parameters.

(3)Model testing: Evaluate the model using R-squared, stable R-squared, non-significance of the Yang-Bockx test, and BIC value.

(4)Model fitting and forecasting: Fit the model to the data and make predictions based on the estimated parameters.

In this study, the selected indicators for time series analysis include YielIn this study, the selected indicators for time series analysis include Yield per Unit Area, Proportion of Cultivated Land Area in Common Use, Mechanical Power per Unit Area, Per Capita Food Possession, Coefficient of Fluctuation in Total Food Production, and Intensity of Fertilizer Use.

Random Forest (RF), also known as random decision trees, is a machineRandom Forest (RF), also known as random decision trees, is a machine learning algorithm proposed by Leo that utilizes tree-based classifiers (Classification and Regression Trees, CRAT) for ensemble classification. As an intelligent modeling tool, RF is not constrained by scale and possesses strong data mining capabilities and high prediction accuracy. It can achieve high classification accuracy based on limited training samples with optimal parameters and minimal error while establishing a weight learning mechanism among multiple variables. This helps to address the issue of overfitting in complex, nonlinear systems.

Furthermore, food security capacity is a complex and large system that is intertwined with land, socio-economic, and ecological factors. Its measurement system is characterized by complexity, non-structure, and random uncertainty, necessitating robust and flexible measurement methods to handle nonlinear relationships, high-order correlations, and even missing values. Additionally, as time and space progress, the influence of various indicators on food security capacity may change, and initial weights may not align with actual conditions, further promoting the development of non-parametric measurement models. RF, as a non-parametric tree-based model, combines all the advantages of previous composite index system measurement methods and exhibits superior performance in handling multivariate nonlinear relationships and dynamic weight changes. It can prevent accuracy reduction caused by noise and data missingness in training samples and theoretically can become an ideal tool for measuring cropland efficiency.

Based on this background, this study aims to construct a random forest model to measure the impact of digital economic development on food security capacity in major grain-producing areas of Ukraine from 2011 to 2022. The proposed model will utilize relevant data sources and indicators to capture the complex interactions between digitalization, economic growth, agricultural productivity, and food security outcomes. By applying RF algorithms, we will be able to analyze the nonlinear relationships and dynamic changes in the selected variables and provide insights into the effectiveness of digital interventions in enhancing food security outcomes in Ukraine's agricultural sector.

In this study, the training set for the random forest model consists of In this study, the training set for the random forest model consists of 54 samples from major grain-producing regions in Ukraine between 2011 and 2021. The dependent variables include Computer Services and Software Professionals, Proportion of Educational Financial Expenditure to Total Financial Expenditure, Per Capita Total Telecommunication Services, Number of Mobile Phone Users per One Hundred People, Number of Internet Users per One Hundred People, Proportion of Scientific Financial Expenditure to Total Financial Expenditure, and Number of Digital Technology-Related Patents per Ten Thousand People.

The test set comprises data from various variables in major grain-producing regions in Ukraine in 2022.

Due to the strong development of global digital technology from 2011 to 2022, the world economic landscape has generally improved. Therefore, this study selects panel data from major grain-producing areas in Ukraine during the period of 2011 to 2022 as the research object to explore the impact of digital technology on food security. The indicator data is mainly sourced from the World Bank organization database, with a small portion coming from the statistical yearbook of the Ukrainian Ministry of Agriculture and the United Nations Economic Development Report. Missing values are filled using linear interpolation. To ensure the stability of variables, this study performs logarithmic transformation on all variables.

Based on the selected data and time frame in this study, the following expBased on the selected data and time frame in this study, the following explanatory variables and explained variables are designed. The explanatory variables include Proportion of Computer Services and Software Professionals, Proportion of Educational Financial Expenditure to Total Financial Expenditure, Per Capita Total Telecommunication Services, Number of Mobile Phone Users per One Hundred People, Number of Internet Users per One Hundred People, Proportion of Scientific Financial Expenditure to Total Financial Expenditure, and Number of Digital Technology-Related Patents per Ten Thousand People. The explained variables include

Yield per Unit Area, Proportion of Cultivated Land Area in Common Use, Mechanical Power per Unit Area, Per Capita Food Possession, Coefficient of Fluctuation in Total Food Production, and Intensity of Fertilizer Use.

5 Comparison of Food Security and Digital Technology Time Series

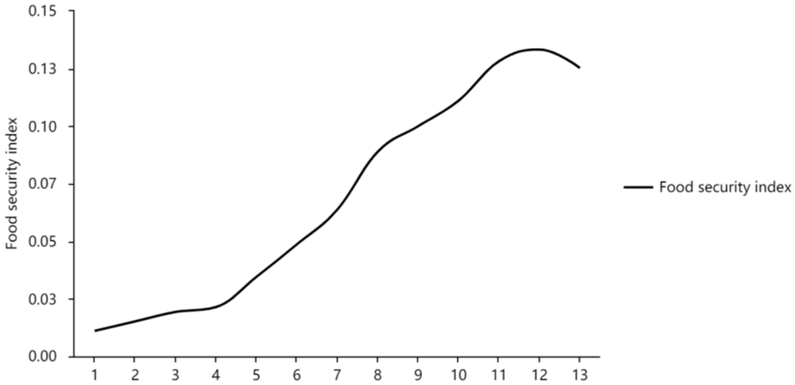

Fig. 1. Temporal evolution of food security in Ukraine.

Ukraine's food security capacity shows a strong growth trajectory. As shown in figure 1, from 2011 to 2022, Ukraine's food security capacity index fluctuates within a range of 0.01 to 0.13. This is largely due to the fact that the Ukrainian government has consistently placed a high priority on food security and has provided a wide range of support, including financial and technical assistance, to this important food-producing region. However, it is worth noting that the Russo-Ukrainian conflict in 2022 had a negative impact on Ukraine's food security index, preventing it from rising further after reaching its peak in that year. Thus we can observe that the Russo-Ukrainian war had a significant negative impact on Ukraine's food security capacity.

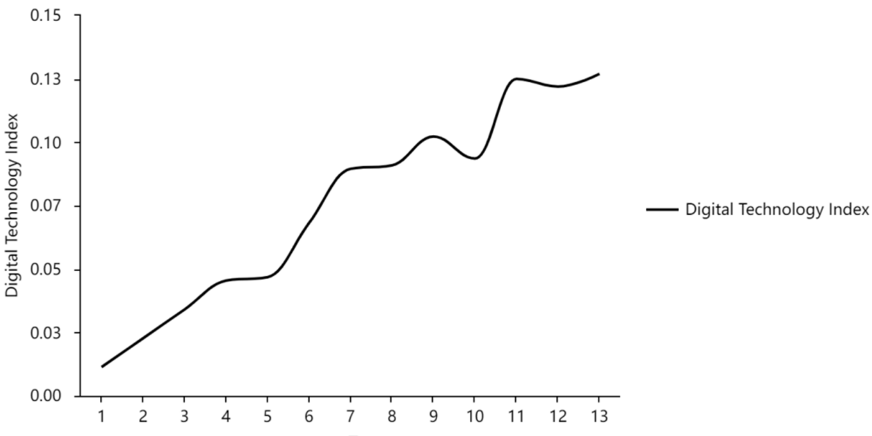

Fig. 2. Ukraine's Digital Technology Evolution Over Time.

The scale of digital technology development in Ukraine is also on the rise. As can be observed from Figure 2, between 2011 and 2022, Ukraine's level of digital technology development fluctuated between 0.01 and 0.136. With the continuous advancement of computer technology, Ukraine's digital technology entered a rapid development phase after 2011, and the scale of digital technology development accelerated and expanded.

By comparing Fig. 1 and Fig. 2 it can be seen that food security capacity and digital technology of Ukraine are on an upward trend during the study period. However, from Figure 1, it can be seen that Ukraine's food security capacity is threatened after the Russian-Ukrainian war in 2022. Thus, it can be observed that food security capacity receives a negative impact of the Russian-Ukrainian war conflict. In conclusion, the temporal changes in Ukraine's food security capacity and digital technology show consistency. Thus, it can be seen that the further development of digital technology can further guarantee food security capacity, and at the same time, the negative impact of the Russo-Ukrainian war on food security can be counteracted by the further development of digital technology.

6 Characteristical and important analysis of the impact of digital technology on food security capacity

Through Figures 1 and 2, it is evident that the development of digital technology has a positive impact on food security capacity. In the following sections, this paper will employ a random forest model to further analyze the feature importance of digital technology in influencing food security capacity.

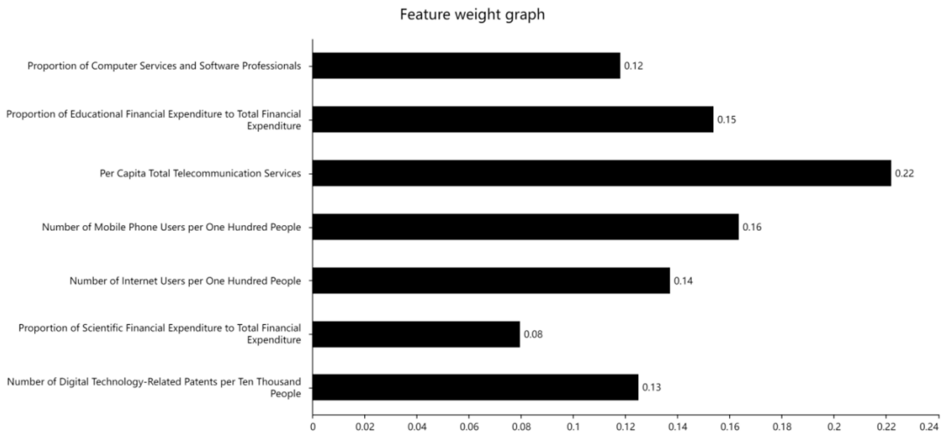

Fig. 3. Feature Importance Chart of the Impact of Digital Technology on Food Security Capacity.

Based on Figure 3, it can be observed that the "Per Capita Total Telecommunication Services" indicator in the Digital Technology Index has the highest impact on food security capability. It plays a significant role in promoting the development of food security capability. On the other hand, the "Proportion of Scientific Financial Expenditure to Total Financial Expenditure" has the least impact on food security capability.

7 Conclusion

This study estimates and analyzes the temporal evolution of food security in Ukraine using a time series approach based on food security data and digital technologies in Ukraine from 2011 to 2022. The study also uses the random forest approach in machine learning to investigate the impact of digital technologies on food security capacity and its underlying mechanisms. The results of the study are as follows: first, from the point of view of global time dynamics, there is a general upward trend in Ukraine's food security capacity, and the differentiation of food security capacity in the regions is expanding, but the Russo-Ukrainian war can lead to the obstruction of food security capacity. At the same time, the level of digital technology development in Ukraine shows a continuous upward trend. Second, observation of the graphs generated by the random forest model reveals that digital technology has a facilitating effect on the development of food security capacity. In addition, the random forest model shows that the indicator "total telecommunication services per capita" has the greatest role in improving food security through digital technologies, while the indicator "the ratio of fiscal expenditure on science to total fiscal expenditure" has the least role. Third, the conclusions drawn from the time series analysis and random forest modeling support the three hypotheses proposed in this study: digital technology affects food security capacity through the production system, the operational system, and the industrial system. In summary, this study provides insights into the changing dynamics of food security in Ukraine and emphasizes the important role of digital technologies in improving food security capacity, with "total telecommunication services per capita" as a key factor in this process. These findings are instructive for policymakers and stakeholders seeking to utilize digital technologies to improve food security.

8 Discussion and Recommendations

Firstly, seize the opportunities of technological transformation and promote the development of digital infrastructure. Technology is the "key way out" for food production, and regions should implement the strategy of "storing grain in the land and in technology" more comprehensively. There should be significant efforts to build new types of infrastructure such as big data, artificial intelligence, and 5G internet. This will expand the coverage of information technology in rural areas, ensure the equitable development of digital technology, narrow the development gap in digital technology, and meet the actual demands of residents for digital services. At the same time, effective matching of supply and demand information in production and marketing links, smooth grain and oil production and marketing channels, and the connection between grain-producing areas and distribution areas are essential.

Secondly, promote the coordinated development of digital technology with urbanization and economic development. Promote the orderly development of new urbanization, further implement strict farmland protection policies, accelerate the construction of high-standard farmland, vigorously promote high-quality economic development in regions, empower digital technology to enhance food security capability, and meet the needs of consumption upgrades.

Thirdly, formulate different development strategies based on local conditions and strengthen cooperation between regions. Promote coordinated development among regions, remove regional barriers, guide the flow of factors, strengthen economic flows between regions, help underdeveloped areas transform from "digital deserts" to "digital highlands," and narrow the "digital divide" between regions. This will better leverage digital technology to enhance food security capability.

Acknowledgments. [Shaanxi Provincial Department of Education Special Project] (21JK0311); [Shaanxi Provincial Social Science Foundation Special Project] (2023SJ10).

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