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Research on the Assessment of the Driving Effect of Digital Technological Innovation on the Income Increasing Efficiency Of Urban and Rural Residents in the Yellow River Basin

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ABSTRACT

The Yellow River Basin is a key region for the national regional coordinated development strategy and the construction of the Belt and Road. Promoting the income increase of urban and rural residents in various provinces of the Yellow River Basin is the key to cultivate new drivers of high-quality development and further promote common prosperity. Using the super-efficient DEA model, this paper analyzes the impact efficiency of digital technology innovation on the income increase of urban and rural residents in nine provinces (autonomous regions) of the Yellow River Basin from 2012 to 2022, and draws the following conclusions: (1) On the whole, the impact efficiency of digital technology innovation on the income increase of urban and rural residents in the Yellow River Basin has not reached the effective level. (2) There are regional differences in the impact efficiency of digital technology innovation on the income increase of urban and rural residents. Areas with superior geographical location, relatively high per capita income and large population can better promote the increase of urban and rural residents' income. (3) In terms of policies, it is necessary to focus on strengthening the infrastructure construction of the Yellow River Basin, further guide and support enterprises to carry out industrial upgrading and transformation, promote the application of digital technology in traditional industries, formulate specific policies and measures according to the characteristics and status quo of each region, comprehensively utilize the advantages of digital technology innovation, and then promote economic development and the improvement of resident income level.

KEYWORDS

Digital economy; Digital technology innovation; DEA model; Income increase of urban and rural residents

1. INTRODUCTION

With the flourishing of the digital economy, the role of digital technological innovation in promoting economic and social development has become increasingly prominent. In particular, in the Circular of the State Council on the Issuance of the Fourteenth Five-Year Plan for the Development of the Digital Economy, the deep integration of the digital economy with the real economy, as well as the importance of digital industrial innovation and the development of the digital service industry, are emphasized. The wide application of digital technology can not only change the traditional mode of production, accelerate the dynamic cycle of the economy and the knowledge spillover effect, but also help to improve the efficiency of the allocation of factors of production.

Academics have conducted extensive and in-depth research on the role of digital technology innovation on income increase. In the quantitative study of digital technological innovation on income

increase, the mediating effect is mostly used to construct regression models [1] and other methods to determine the impact of digital technological innovation infrastructure on income. From the perspective of models [2] and research perspectives, scholars have studied the application of digital technology in the rural economy [3-4], the role of mechanisms and paths for realizing common wealth [5], and the application of digital technology in the digital transformation of enterprises [6-7], but the issue of the high efficiency of the impact of digital technological innovation on the increase in income of urban and rural residents has not yet been widely studied, and an in-depth study of the impact of digital technological innovation on the measurement of the efficiency of urban and rural residents' income increase is of great significance for accurately identifying the weak links of digital infrastructure construction and accelerating the improvement of urban and rural residents' income. At present, there are relevant studies on the efficiency of income increase from different scales such as province, city and county. In the context of China attaches great importance to the development of digital economy, the Yellow River Basin, as an important agricultural region of the country, has rich land resources and agricultural industries, and digital technological innovation is regarded as a potential driving force that can promote the transformation and upgrading of the economy of the Yellow River Basin and the increase of residents' income.

Based on the provincial scale, this study applies the super-efficiency DEA research method to measure in-depth the efficiency of income increase of urban and rural residents in the Yellow River Basin, aiming to analyze the specific impacts of digital technological innovation inputs on the income growth of urban and rural residents in the Yellow River Basin, to reveal the differences between urban and rural residents in terms of the efficiency of income increase and the increase in income, and to analyze the heterogeneity of the increase in the income of urban and rural residents in different provinces from the perspective of the spatial and temporal evolution, in order to provide suggestions for the Yellow River Basin to Provide suggestions for digitizing income increase of urban and rural residents.

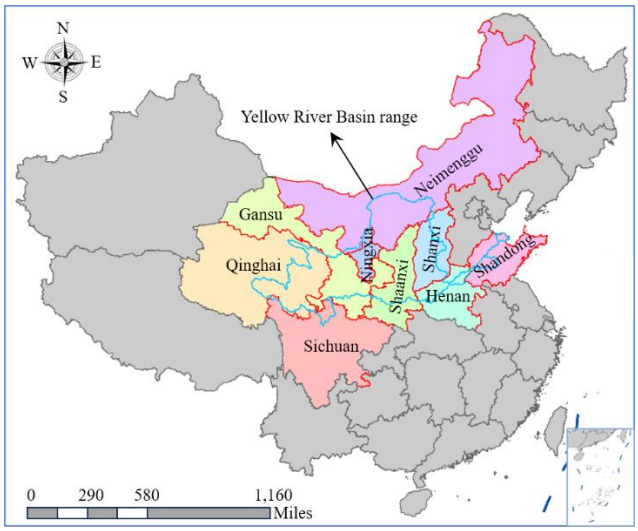

Figure 1. Map of Nine Provinces (Regions) in the Yellow River Basin

2. RESEARCH OBJECT

The urban and rural residents of the Yellow River Basin cover nine provinces and autonomous regions in China, with a concentrated agricultural population in the region, a single economic structure, high resource dependence, and a relatively low level of residents' income. In 2019 and 2021, General Secretary Xi Jinping convened two symposiums to elevate the ecological protection and high-quality development of the Yellow River Basin to a major strategy at the national level. This paper chooses the income of urban and rural residents in nine provinces (regions) in the Yellow River Basin as the

research object, explores the efficiency of the impact of digital technological innovation on the income of urban and rural residents, and evaluates whether the digital technological innovation in the region plays an effective role from the perspective of inputs and outputs, so as to lay a solid theoretical foundation for the high-quality development of the economy and society of the Yellow River Basin.

3. RESEARCH DESIGN

3.1. Research Methodology

3.1.1. Super-efficiency DEA modeling

Data Envelopment Analysis (DEA) is widely used in the study of efficiency measurement [8]. It calculates the input-output efficiency by means of linear programming, and can analyze the impact of pure technical efficiency and scale efficiency on the ineffective state of DEA at the same time. It is especially good at dealing with the complex efficiency evaluation problem of multiple inputs and multiple outputs, which makes it very suitable for analyzing the complex regional logistics efficiency [9]. In order to break through the limitation of the upper limit of 1 set in the traditional DEA model, Andersen and Peterson [10] proposed the super-efficiency DEA model. The super-efficient SBM model further integrates the advantages of traditional DEA and SBM models, thus providing a more accurate measure of input-output efficiency. At the same time, the model also allows the comparison of multiple effective decision units [11-12], which in turn realizes a comprehensive assessment of the efficiency level of decision units. In view of this, this paper uses the super-efficiency DEA model to perform calculations aimed at more accurately assessing the efficiency level of each effective decision unit.

Assuming that there are *n* decision making units (Decision Making Unit), each decision making unit has s outputs Y_{rj} (r=1, 2, ..., s) under m inputs X_{ij} (i=1, 2, ..., m), and its expression is as follows:

$$\text{s.t.}\sum_{\substack{j=1\\ j\neq 0}}^{n}\lambda_j X_{ij} + S_i^- = \min\theta_0^{super} \tag{1}$$

$$\sum_{\substack{j=1\\ j\neq 0}}^{n}\lambda_j Y_{ij} + S_r^+ = Y_{r0} \tag{2}$$

$$\sum_{j\neq 0}^{n}\lambda_j = 1 \tag{3}$$

$$\lambda_j, S_i^-, S_r^+ \geq 0,\ j \neq 0 \tag{4}$$

Where: $min\theta_0^{super}$ is the target efficiency value, 0 is the DMU being measured; λ_j is the weight of each DMU, each DMU has *m* input indicators, S_i^- and S_r^+ are the slack variables of inputs, desired outputs, respectively, and the larger the value of $min\theta_0^{super}$, the higher the efficiency of digital technological innovations in increasing the incomes of urban and rural residents in the Yellow River Basin, and vice versa, the lower it is.

3.1.2. Malmquist index

Malmquist index was originally proposed by Malmquist [13] and later, scholars such as Caves and others [14] applied it to the calculation of productivity change, which led to the Malmquist index model. The model can be used to assess the continuous dynamic changes in the efficiency of a decision unit over a certain period of time. The model is measured by comparing the productivity changes in the previous and later periods, thus reflecting the changes in the efficiency of decision-making units [15]. In order to more objectively analyze the dynamic evolution of the efficiency of

urban and rural residents' income growth in the nine provinces of the Yellow River Basin, we adopt the Malmquist index model to dynamically measure and systematically analyze the income efficiency with the following expression:

$$M\left(x^{t+1}, y^{t+1}, x^{t}, y^{t}\right)=\left[\frac{D^{t}\left(x^{t+1}, y^{t+1}\right)}{D^{t}\left(x^{t}, y^{t}\right)} \times \frac{D^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D^{t+1}\left(x^{t}, y^{t}\right)}\right]^{\frac{1}{2}} \tag{5}$$

$$E_{ffch}=\frac{D^{t}\left(x^{t+1}, y^{t+1}\right)}{D^{t}\left(x^{t}, y^{t}\right)} \tag{6}$$

$$T_{ech}=\left[\frac{D^{t}\left(x^{t+1}, y^{t+1}\right)}{D^{t+1}\left(x^{t+1}, y^{t+1}\right)} \times \frac{D^{t}\left(x^{t}, y^{t}\right)}{D^{t+1}\left(x^{t}, y^{t}\right)}\right]^{\frac{1}{2}} \tag{7}$$

$$T_{fpch}=E_{ffch} \times T_{ech}=\left(P_{ech} \times S_{ech}\right) \times T_{ech} \tag{8}$$

Where: x^{t}, y^{t} and x^{t+1}, y^{t+1} denote the input-output vectors in period t and period t+1, respectively. If the M-index is greater than 1, it indicates that the efficiency has improved; conversely, it indicates that the efficiency has decreased.

3.2. Research Steps

This study adopts the super-efficiency DEA method to deeply analyze the efficiency correlation between digital technological innovation and urban and rural residents' income increase in nine provinces (districts) in the Yellow River Basin during the period of 2012-2022. First, relevant data are systematically collected and organized to construct a data set covering multi-dimensional indicators of digital technology innovation and urban and rural residents' income increase. Subsequently, a super-efficiency DEA model was used to measure the efficiency of these data, revealing the efficiency of digital technological innovation on urban and rural residents' income growth and its regional differences. Finally, based on the results of the study, targeted policy recommendations are put forward.

4. DATA SOURCES AND INDICATOR SYSTEM

4.1. Data Sources

This study adopts the 2012-2022 HBN Yellow River Basin Development Database and the annual data of the National Bureau of Statistics by province. Given that the 2022 data on urban unit employment of the information transmission, software and information technology service industry in each province has not yet been released, in order to ensure the completeness of the data, this study utilizes the SPSS software to make up for the missing values by the linear trend-filling method, which provides a reliable data for the subsequent analysis. The study utilizes SPSS software to fill in the missing values through the linear trend filling method, providing a reliable data basis for the subsequent analysis.

4.2. Indicator System

Regarding the selection of digital technology innovation indicators, given that the current literature involving digital economy measurement is relatively small and mainly focuses on provincial-level research, a unified and widely recognized method for measuring the level of digital technology innovation has not yet been formed. This paper combines the availability of data with the selection of input indicators, referring to the studies of Liu Jun et al [16], Zhao Tao et al [17], Bo Peiwen and Zhang Yun [18], Bukht & Heeks [19], and the China Academy of Information and Communication Technology (AICT), and the selection of output indicators, referring to the studies of Xu Huilin [21], to select the following indicators to measure the efficiency of the digital technological innovation driven by the income of urban and rural residents in the Yellow River Basin The efficiency of the program is measured (as shown in Table 1).

Table 1. The efficiency impact of digital technology innovation on income increase for urban and rural residents input output indicators

Model	Form	Indicator name	Notation
DEA model	Input indicators	Fiber optic line length	X_1
		Mobile telephone exchange capacity	X_2
		Number of broadband access users	X_3
		Employed in urban units of the information transmission, software and information technology services industry	X_4
		Number of patent applications received	X_5
		R&D expenditures of industrial enterprises above designated size as a share of GDP (%)	X_6
	Output indicators	Per capita disposable income of urban residents	Y_1
		Per capita disposable income of rural residents	Y_2

By strengthening infrastructure, expanding the scope of application and promoting industrialization, digital technological innovation has contributed to increased employment opportunities and higher labor productivity for urban and rural residents, thereby positively affecting economic growth and income growth. Specifically, the enhancement of communications infrastructure has helped to break down information barriers and increase market connectivity, laying the foundation for the widespread application and industrialization of digital technologies, and enriching the ways in which urban and rural residents can increase their incomes. Employment growth in the information transmission, software and information technology service industry has helped urban residents' income grow steadily. The increase in the number of patent applications received reflected the enhancement of the country's innovation capability, providing fertile ground for innovative activities by enterprises and individuals. The increase in the proportion of R&D expenditure of industrial enterprises in GDP promotes technological progress and provides impetus for the sustained growth of residents' income. In short, digital technological innovation contributes to economic growth and rising incomes through a variety of factors.

5. RESULTS AND ANALYSIS

5.1. Mechanism Analysis of Digital Technology Innovation Affecting Income Increase

Digital technology innovation affects the income level of urban and rural residents through multiple paths (Fig. 2), with the following specific mechanisms:

(1) Digital technological innovation has enriched the source of income of residents, through e-commerce, online retail and other online economic models, expanding the employment and entrepreneurial opportunities of urban and rural residents, thereby enhancing their income potential.

(2) Digital technological innovation has effectively reduced the cost of residents' expenses, and with the help of mobile payment, sharing economy and other means, it realizes convenient, efficient and low-cost access to services and products, and improves the consumption ability and quality of life.

(3) Digital technological innovation significantly improves regional production efficiency. Through the wide application of digital technology and the deep integration of data and other factors of production, it promotes the improvement of productivity and efficiency, accelerates the integration of markets and the overflow of knowledge, and then improves the efficiency of technological innovation.

(4) Digital technological innovation helps to promote the integrated development of urban and rural areas, optimize the allocation of resources through digital platforms, unimpeded the exchange of information between urban and rural areas, promote complementary and synergistic economic development, and narrow the gap between urban and rural areas.

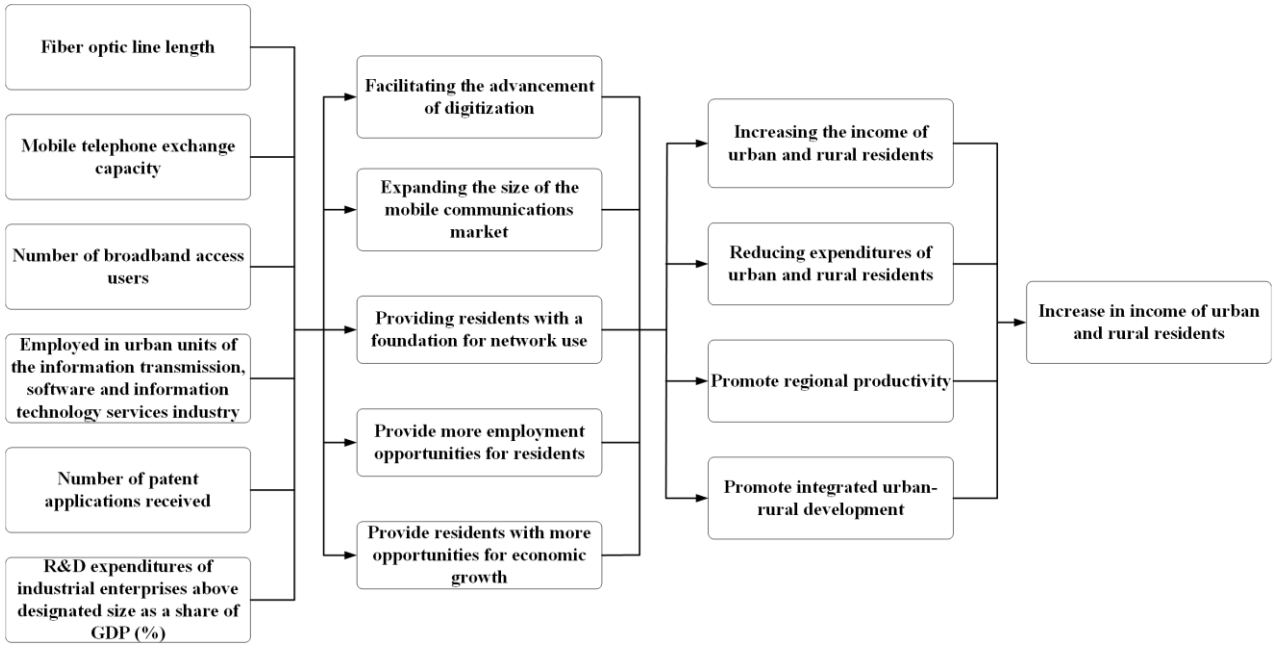

Figure 2. Mechanism analysis of the impact of digital technology innovation on income growth

5.2. Efficiency of the Impact of Digital Technology Innovation on Income Increase of Urban and Rural Residents in the Yellow River Basin

This paper adopts the output-oriented SBM model to quantitatively measure the efficiency of digital technological innovation on income increase of urban and rural residents in nine provinces (regions) in the Yellow River Basin from 2012 to 2022 (Fig. 3). The results show that: 1) The overall efficiency values of the Yellow River Basin are lower than the production frontier, indicating that the optimal state has not yet been reached, but the efficiency level is relatively stable, without any significant upward or downward trend. 2) At the regional level, except for Shandong and Shaanxi, the differences in efficiency between provinces and regions are not significant. In particular, Shaanxi is initially less efficient, but then shows a growing trend. Overall, the gap between the highest and lowest efficiency values in each province and region narrowed from 0.331 to 0.173, indicating that the efficiency gap between regions is gradually narrowing.

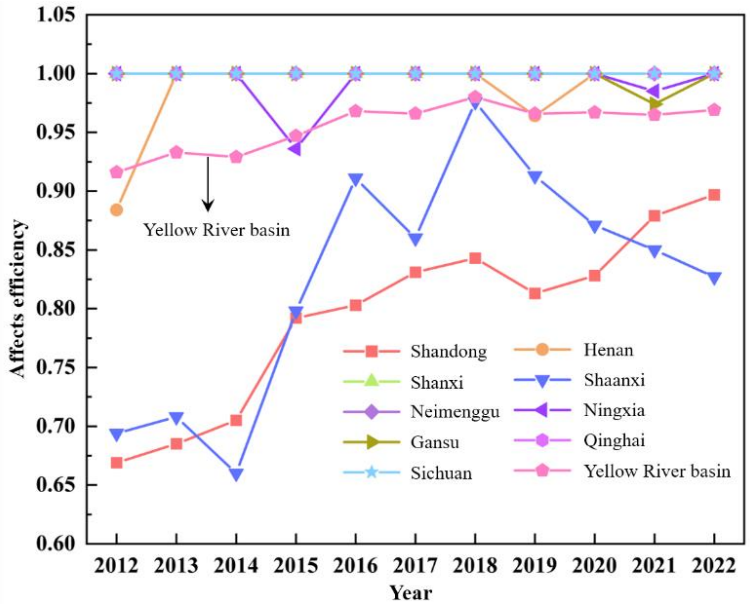

Figure 3. The average efficiency of digital technology innovation in the Yellow River basin affects the income increase of urban and rural residents

The efficiency values of the efficiency measures of digital infrastructure on income increase of urban and rural residents in each province and region are graded and evaluated into five levels: level 1 (≥1), level 2 [0.90, 0.99), level 3 [0.80, 0.89), level 4 [0.70, 0.79), and level 5 [0, 0.69), as shown in Fig. 4.The results of the evaluation show that: digital technological innovations in the nine provinces of the Yellow River Basin have a greater impact on urban and rural residents' The efficiency of the impact of increasing income has a greater impact on the middle and lower reaches of the Yellow River Basin.

(1) The efficiency of the impact of digital technological innovation on the income increase of urban and rural residents is higher in the middle and upper reaches of the Yellow River region, which are relatively independent of the maritime trade system and rely more on digital technological innovation to enhance the efficiency of the income increase of urban and rural residents. In contrast, although the middle and lower reaches of the Yellow River are closer to domestic and foreign markets and technological innovation centers, the improvement of the efficiency of urban and rural residents' income increase is not obvious due to factors such as population density and industrial structure.

(2) Regions with higher income levels excel in digital innovation driving income growth for urban and rural residents, thanks to a well-developed innovation ecosystem and economic foundation. On the contrary, the impact of digital innovation on income growth is weaker in regions with lower income levels due to relatively lagging economic development and a single industrial structure.

(3) Regions with larger populations are also more efficient in increasing the income of urban and rural residents driven by digital technology innovation. Because digital technology can satisfy personalized needs and provide diversified products and services, it stimulates the growth of consumer demand and promotes economic prosperity, creating more opportunities for urban and rural residents to increase their income.

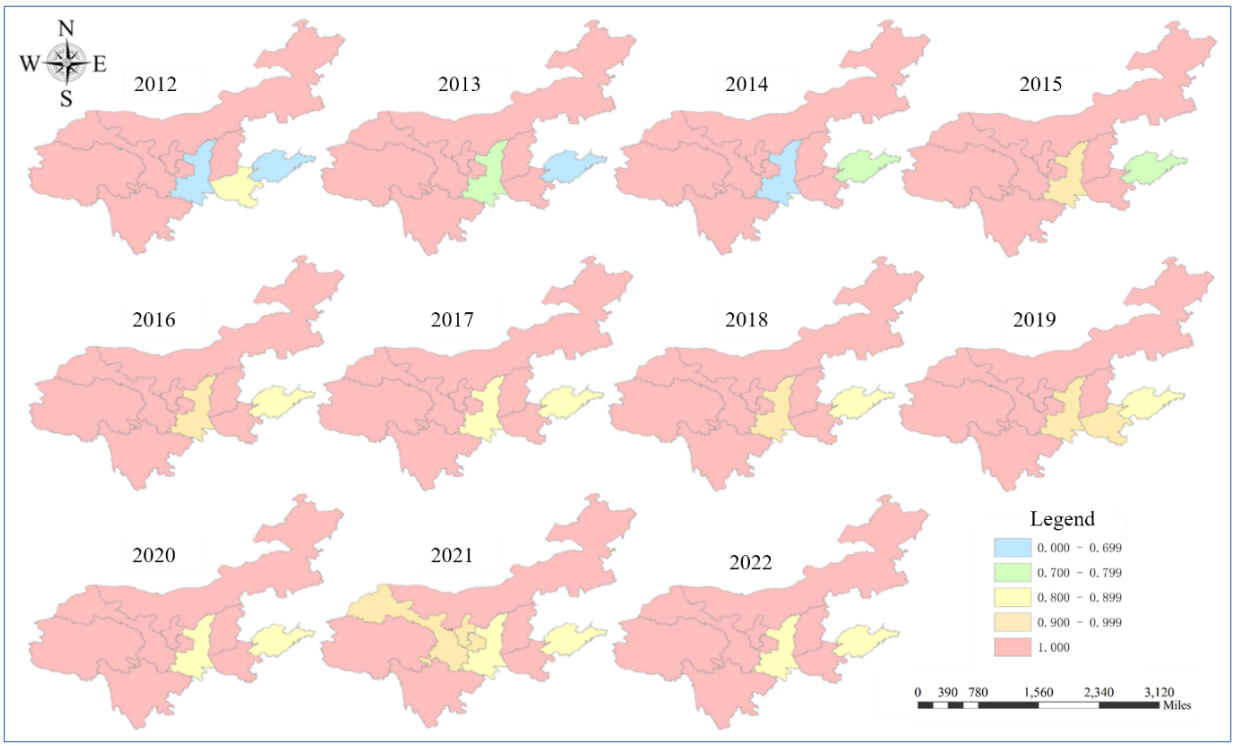

Figure 4. The impact of digital technology innovation on the income increase of urban and rural residents in the Yellow River Basin in 2012-2022

5.3. Dynamic Analysis of the Impact of Digital Technological Innovation on the Efficiency of Income Increase of Urban And Rural Residents in the Yellow River Basin

Malmquist index can effectively assess the dynamic change of the efficiency of the impact of digital technological innovation on the income increase of urban and rural residents in the Yellow River Basin. The relevant data of nine provinces (regions) in the Yellow River Basin from 2012 to 2022 are measured and analyzed, and the results are shown in Table 2 and Fig. 5.

Table 2. The impact of digital infrastructure in the Yellow River Basin on urban and rural residents' income increase in 2012-2022 Malmquist index and decomposition

Year range	Technical efficiency	Technological progress	Pure technical efficiency	Scale efficiency	Efficiency of production
2012-2013	1.019	0.905	1.009	1.009	0.922
2013-2014	0.995	1.072	0.992	1.003	1.067
2014-2015	1.027	0.974	1.029	0.998	1
2015-2016	1.024	1.029	1.031	0.993	1.054
2016-2017	0.997	1.077	0.991	1.007	1.074
2017-2018	1.016	0.978	1.01	1.005	0.993
2018-2019	0.985	1.045	0.997	0.987	1.029
2019-2020	1.001	0.965	1.001	1	0.966
2020-2021	0.999	0.959	1.002	0.997	0.958
2021-2022	1.004	1.046	0.993	1.011	1.05
Average value	1.007	1.004	1.006	1.001	1.01

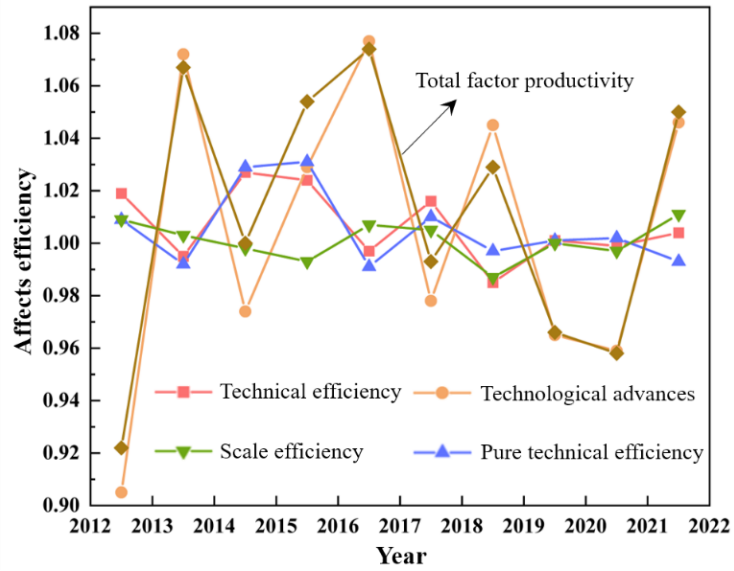

Figure 5. The evolution of the efficiency effect of digital infrastructure on the income increase of urban and rural residents in the Yellow River Basin

During the period under examination, the average value of the total factor productivity index of digital technological innovation on income increase in the Yellow River Basin was 1.01, showing an upward trend. Among them, productivity increased significantly in 2013-2014 and 2016-2017, reaching 6.7% and 7.4% respectively. This is attributed to the rapid development of the Internet finance industry and the popularization of mobile payment as a result of the country's comprehensive deepening reform, and the improvement of urban and rural residents' infrastructures and livelihood security; however, productivity declined during 2019-2021 due to the impact of the New Crown Epidemic and the instability of the global economy, but rebounded after 2021.

In terms of disaggregated indicators, the degree of digital technology utilization in the Yellow River Basin shows a continuous upward trend, in which the technical efficiency increases by an average of 0.7% per year, mainly driven by technological progress. Among them, the increase is the largest in 2016-2017, at 7.7%, but declines of different degrees occur between 2017-2022. Pure technical efficiency declines over multiple time periods, suggesting that factors such as management and skill levels are limiting production efficiency. Scale efficiency grows the slowest, with the scale expansion effect weakening in some time periods.

The productivity growth rate in the Yellow River Basin varies significantly across years, with the largest decline in 2012-2013, when technical progress slipped by 7.8%, becoming the main cause of the decline in technical efficiency. Since 2015, productivity has gradually increased, thanks to the strengthening of the national digital construction policy. during 2015-2021, the contribution of pure technical efficiency is significant, but technical progress fluctuates greatly, affecting the stable growth of productivity. By 2021-2022, all efficiencies except technical efficiency have increased, with significant progress in the area of digital technology, which in turn improves productivity and product quality. Overall, fluctuations in technological progress have a significant impact on productivity, and policy guidance and technological innovation need to be continuously strengthened to ensure a steady increase in efficiency.

Taken together, all indicators show fluctuating changes, with greater volatility in technological progress. This, together with the combined effects of other factors, has led to a lack of sustainability in income growth and productivity growth. Therefore, in the future, in the process of promoting digital technological innovation and income increase of urban and rural residents in the Yellow River Basin, it is necessary to pay attention to the continuity and stability of policies, as well as the continuous innovation and optimization of technology, so as to ensure the steady improvement of the efficiency of income increase.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

Through the empirical research on the measurement of the efficiency of digital base innovation on income increase of urban and rural residents in the Yellow River Basin from 2012 to 2022, the following conclusions can be drawn:

(1) Although digital technological innovation in the Yellow River Basin has a certain effect in promoting the income increase of urban and rural residents, the overall efficiency has not yet reached the ideal state, and there are obvious regional differences. In particular, the middle and lower reaches are significantly affected by digital technology innovation, while the lower reaches are relatively small. Factors such as geographic location, per capita income level and population size have an important impact on the efficiency of digital technology innovation in promoting income generation. Shaanxi and Shandong are outstanding in digital technology innovation for income generation, while Shanxi, Inner Mongolia, Qinghai and Sichuan are relatively weak. In addition, there is a non-linear relationship between the level of residents' income and the efficiency of the impact of digital technology innovation, with higher efficiency in high-income areas and lower efficiency in low-income areas.

(2) The efficiency growth of urban and rural residents' income in the provinces and regions of the Yellow River Basin shows significant volatility and lack of stability. Technological progress has the greatest fluctuation in the impact of income growth, resulting in significant changes in productivity. Although Shandong Province is more efficient, it is not ideal, and Shaanxi Province also lacks stability, although its performance is outstanding in some years. Total factor productivity shows the fluctuating characteristics of “rise-fall-rise”, and the fluctuation of technical efficiency is especially significant, which becomes a key factor affecting total factor productivity. To summarize, digital technology innovation in the Yellow River Basin is both effective and problematic in promoting the income of urban and rural residents. In the future, policy guidance and technological innovation should be strengthened, and the regional application mode of digital technology should be optimized to achieve more efficient and stable income-generating effects.

6.2. Suggestions

Aiming at the problems in the efficiency measurement of digital technology innovation driving the income increase of urban and rural residents in the Yellow River Basin, the following countermeasures are proposed:

(1) Enhance the level of digital infrastructure in the Yellow River Basin, strengthen network coverage and infrastructure construction, especially for the provinces and regions with lower efficiency, network layout should be optimized and hardware facilities should be upgraded, so as to break the digital divide and promote the balanced development of regional economy.

(2) Promote the digital transformation of agriculture, use modern information technology to realize intelligent and refined management of agricultural production, improve agricultural production efficiency, optimize the structure of agricultural products, expand sales channels, and increase the income of rural residents.

(3) Tap the advantages of characteristic industries, combine the resource endowment and industrial foundation of the Yellow River Basin, enhance the added value and market competitiveness of characteristic industries through digital technological innovation, and promote the diversified development of the regional economy.

(4) Implement differentiated policies, formulate targeted strategies and action plans based on the differences in digital technological innovation in different regions within the Yellow River Basin,

and strengthen digital education and skills training to enhance the digital literacy and application capabilities of urban and rural residents.

In summary, by upgrading digital infrastructure, promoting the digital transformation of agriculture, tapping into the advantages of specialty industries and implementing differentiated policies, the problems of digital technological innovation in the Yellow River Basin in driving the measurement of the efficiency of urban and rural residents' income increase can be effectively solved, and the sustained and healthy economic and social development of the Yellow River Basin can be promoted.

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