Evaluating Digital Financial Inclusion's Impact on Regional Economic Efficiency in China

Abstract:

Digital financial inclusion helps bridge regional financial service gaps, reshapes labor allocation, and boosts overall economic efficiency. This study explores its theoretical framework and impact on regional economic efficiency using provincial panel data from China (2011–2020). Findings indicate that digital financial inclusion significantly enhances economic efficiency by alleviating financial exclusion—particularly when supported by strong transportation infrastructure and traditional financial systems. It improves access to resources in underdeveloped regions and among disadvantaged groups. This positive effect is most pronounced in areas with a solid foundation of economic and financial development. Furthermore, digital financial inclusion promotes entrepreneurship and helps narrow regional education disparities, further contributing to economic efficiency.

Keywords: Digital Financial Inclusion; Regional Economic Efficiency; Mechanism of Influence

1. Introduction

Since the reform and opening up, China's investment-driven economic growth model has led to rapid economic expansion. This growth has been fueled by significant foreign capital inflows, contributing to rapid urbanization and industrialization(Y. Zhang & Xie, 2019). The primary input factors—such as capital, labor, and land—have predominantly flowed into urban areas and large to medium-sized enterprises, which are more efficient. However, China's economic development is now confronted with both internal and external constraints. Externally, the global economy is experiencing slower growth and high inflation. Internally, challenges include insufficient domestic demand, weakened expectations, and rising risks. Additionally, the pace of urbanization has slowed, the marginal productivity of factor inputs has begun to decline, and economic growth has shifted to a medium-high speed. This indicates that the investment-driven growth model needs to transition to an intension-intensive development model. Changing the growth model requires enhancing the productivity of producers, particularly across different regional organizations. While maintaining production efficiency in developed regions, factors with declining marginal productivity should be reallocated to the production organization of underdeveloped regions. This reallocation will help reshape the regional division of labor and improve overall economic efficiency.

According to the theory of cumulative causality, once factors become excessively agglomerated due to the 'backwash effect', a subsequent 'spread effect' will gradually emerge. This spread effect allows underdeveloped regions and groups to better allocate resources, thereby increasing the value generated from these inputs and improving overall regional economic efficiency. However, in China's current market economy development system, 'backwash effect' is generally stronger than 'spread effect' (Hur, 2018). Therefore, it is essential to establish mechanisms that can effectively accelerate the spread process and thereby enhance regional economic efficiency. Digital financial inclusion leverages digital technology to extend financial services to vulnerable groups with limited financial access, such as low-income populations. In China, it has significantly enhanced the availability and convenience of financial services in rural areas, marking a new phase in the development of financial inclusion (Xun et al., 2020). By enhancing social security, the government not only promotes regional economic equity but also boosts overall economic efficiency, achieving a balance between equity and efficiency (Vanderhart, 2003). Financial inclusion, as a key component of China's financial reform, serves as a government intervention aimed at

increasing financial service accessibility for underserved groups. As a top-down policy tool, it has a notable impact on regional economic efficiency. Digital financial inclusion is an innovative financial tool that combines digital technology with an inclusive approach, focusing on demand-side utilization (Guo et al., 2020). By leveraging digital technology, it lowers the barriers for the general population to access financial services. In areas with inadequate financial services and among marginalized groups, digital financial inclusion allows individuals to spontaneously acquire financial services, thereby improving their living and production conditions. The financing needs of financially vulnerable groups, such as small and medium-sized enterprises, can be more effectively addressed through digitalization instead of traditional approaches, which improves financial inclusion (X. Zhang et al., 2023). At the macro level, digital financial inclusion functions as an inclusive mechanism which is more effective targeting financially vulnerable groups. This mechanism alleviates financial constraints in underdeveloped regions, facilitates the flow of production factors to vulnerable areas and marginalized groups where production efficiency can be more readily enhanced through financial resources, and mitigates efficiency losses from the excessive agglomeration of production factors in developed regions. Consequently, it strengthens the 'spread effect,' thereby improving overall regional economic efficiency. As a new financial tool concerned with equity, what is the impact of digital financial inclusion on regional economic efficiency? Can it influence regional economic efficiency by accelerating factor spread, improving the effectiveness of factor allocation, or altering production structures? Furthermore, how does it relate to traditional financial development in this context? To address these questions, this paper uses Chinese provincial panel data from 2011 to 2020 to evaluates digital financial inclusion's impact on regional economic efficiency in China and to clarify the mechanisms through which digital financial inclusion affects this efficiency. This paper mainly focuses on the impact of digital financial inclusion on the conversion efficiency of regional input and output. It investigates whether the enhanced financial accessibility provided by digital financial inclusion to underdeveloped regions and groups can improve the effectiveness of factor allocation within provincial areas, thereby reducing excessive agglomeration in developed regions and groups. As a result, producers can operate closer to the production frontier given current technological conditions, thus enhancing regional economic efficiency. This is consistent with the concept of Technical Efficiency (TE). The reduction of excessive agglomeration is essentially reflected as an improvement in technical efficiency. Consequently, the core of this paper's analysis is to isolate the effects of technical progress and allocative efficiency within Total Factor Productivity (TFP) and use technical efficiency

as the measure of economic efficiency.

This paper selects provincial-level regions in China for the period 2011-2020 for the following reasons. First, since the reform and opening up, China's economy has experienced rapid growth and has become the world's second-largest economy. However, regional economic development in China remains highly imbalance, and there must be excessive agglomeration of factor resources, which is the background of this paper. Second, between 2011 and 2020, China undertook significant efforts to transform its economic drivers and address development imbalances. During this period, financial inclusion and digital finance saw substantial growth, providing a relevant context for this study. Third, China's provincial regions cover a vast geographical area and exhibit significant disparities in economic development, which facilitates the examination of the influence mechanisms that this paper aims to investigate.

The marginal contributions of this paper are threefold: First, this paper emphasizes the 'inclusion' aspect of digital financial inclusion. It examines, from the perspective of technical efficiency, whether digital financial inclusion can improve factor allocation in provincial regions and among groups with excessive factor agglomeration and poor availability. This, in turn, affects regional production efficiency and promotes overall economic efficiency. This offers new insights for better playing the role of digital financial inclusion in promoting regional economic efficiency. Second, existing research on the relationship between digital financial inclusion and regional economic efficiency predominantly focuses on Total Factor Productivity (TFP) and the efficiency of financial services in the real economy. Many studies suggest that technological progress is a major driver of TFP growth in China, while improvements in technical efficiency remain limited. Based on the influence mechanism of digital financial inclusion, this paper studies the relationship between the two from the perspective of technical efficiency. This not only provides new perspectives on enhancing technical efficiency but also expands the research on digital financial inclusion and regional economics. Third, while Total Factor Productivity (TFP) is commonly used to measure economic efficiency, improving its three-component technical efficiency, technological progress, and allocative efficiency—requires distinct strategies to enhance overall TFP effectively. Current research often focuses on regional economic efficiency as represented by TFP. However, the increase in TFP due to technological progress may mask the decline in technical efficiency caused by excessive agglomeration. The profit-seeking of production

factors makes them continue to gather in developed regions and groups, further causing excessive agglomeration and hinders the improvement of technical efficiency and TFP. This paper uses technical efficiency as a measure of regional economic efficiency to better understand the phenomenon of excessive agglomeration in China and its associated efficiency losses. By isolating the effects of technological progress and other factors, this study aims to clarify the underlying mechanisms and explore new strategies for improving regional economic
efficiency.

2. Literature review

As a key indicator of high-quality economic development, economic efficiency has been extensively studied both theoretically and empirically in recent years. The academic consensus recognizes that multiple factors influence economic growth efficiency. In the financial domain, the financial system plays a crucial role by facilitating information collection, risk diversification, reducing information and transaction costs, and directing the flow of financial resources, thereby impacting economic efficiency. This paper reviews and evaluates the relevant research on digital financial inclusion and economic efficiency from three perspectives.

2.1. Research on the measurement and influencing factors of economic efficiency

Measuring economic efficiency begins with a clear understanding of the concept of efficiency. Beyond the well-known Pareto efficiency, Kaldor-Hicks efficiency posits that, in the short term, the gains of one party may result in the welfare loss of another, but as long as this loss can be compensated in the long term, overall efficiency can still be improved (Coleman, 2010; Lawson, 1992). In efficiency analysis, it is generally accepted thatefficiency can be broken down into technical efficiency and technological progress, which together are used to assess productivity (Färe et al., 1985; Fare et al., 1994). Currently, the most widely accepted definition of economic efficiency is that it represents the allocation rate of resources and measures the extent to which economic needs are satisfied for individuals and society (Eatwell, 1996). In China, the concept of economic efficiency is often aligned with Pareto efficiency, focusing on the rational allocation of resources and minimizing waste (X. Yang et al., 2023). Based on this, economic efficiency can be regarded as a form of productivity, with its specific connotations

reflected in the existing measurements of economic efficiency. Currently, there are two primary methods for measuring economic efficiency. The first method views economic efficiency as the ratio of input to output, representing total productivity. The key measure in this category is Total Factor Productivity (TFP), as well as some other efficiency indicators, which are calculated using input and output factors while accounting for technological progress, allocative efficiency, and other indicators (Keng & Li, 2010). For example, (Farrel, 1957; Fried et al 1993) developed three measurement models technical parameters, non-parametric technology (DEA), and stochastic DEA models to assess productivity. In contrast to DEA, which determines the production frontier based on observed data, the Stochastic Frontier Approach (SFA) requires specifying a frontier model. SFA assumes a certain distance between an individual's production and the ideal production frontier, with this distance representing efficiency loss. (Miller, 2002) further elaborate on SFA, using it to incorporate technical efficiency into production function models and estimate the potential for trade improvements by measuring trade efficiency. Alternatively, some scholars argue that measuring economic efficiency through total productivity can be imprecise and prone to bias. They suggest using factor productivity, such as labor productivity, as a more reliable measure of economic efficiency (Remy,1999) .

Existing international literature highlights that economic efficiency is influenced by numerous factors, particularly regional economic variables. In developed countries like the United States, government interventions that lead to varying prices for the same production factor across regions can cause significant resource misallocation, potentially reducing TFP by 30%-50% (Restuccia & Rogerson, 2008). A study encompassing over 190 countries globally finds that infrastructure, finance, technology, and human development all impact TFP growth to varying degrees, with unobservable technological progress remaining the most critical component of TFP growth (Heshmati & Rashidghalam, 2019). In underdeveloped regions, such as sub-Saharan Africa, foreign direct investment has been shown to effectively boost TFP, with human capital and environmental governance playing positive roles in this nonlinear process (Kariuki & Kabaru, 2021). Through both theoretical analysis and empirical testing, Chinese scholars have identified various effective strategies for improving economic efficiency. From a macroeconomic perspective, while East Asia's rapid economic growth before 2000 was primarily driven by input factors, technology and efficiency have been shown to be the most significant sources of real output growth (DRYSDALE & HUANG, 1997). Additionally, productivity growth has been recognized as a major contributor to economic

growth (Fu & Gong, 2009). Currently, China is transitioning from a dual economic development stage to a neoclassical growth stage, making the investment-driven economic development model unsustainable. This shift necessitates adjustments in development strategies to enhance resource reallocation efficiency and transition to a growth model supported by Total Factor Productivity (TFP) (Cai, 2013). Finance plays a crucial role in effectively guiding resource flow. TFP, as a key indicator of economic efficiency, is influenced by technological progress, technical efficiency, and industrial structure transformation (Li, 2016). Current academic research on economic efficiency explores influencing factors through these three main approaches. First, there is an inverted U-shaped relationship between industrial structure transformation and TFP, with China's degree of structural transformation still positioned to the left of the inflection point (Liu and Ling, 2020). Specifically, within the manufacturing sector, structural improvement negatively impacts economic growth efficiency, whereas rationalization of the manufacturing structure has a positive effect (X. Liu, 2020). However, in the early development stage, the relationship between structural upgrading in China's manufacturing industry and labor productivity is not significant (L. Wang & Szirmai, 2008). Second, technological progress is strongly supported by innovation (F. Luo et al., 2022), and regional technology transfer also plays a critical role in advancing regional technological progress (Changfu & Miaomiao, 2023). Effective configuration of R&D resources not only enhances TFP in a given region but also generates spatial spillover effects (KATAOKA, 2012). Third, regarding technical efficiency, improvements in resource allocation effectiveness and advancements in digital technology have directly contributed to increased macroeconomic efficiency (Dong & Liu, 2022). There is an inverted U-shaped relationship between resource industry dependence and TFP (Shao et al., 2013), indicating the counterproductive effects of over-allocated resources. Additionally, to explore strategies for improving technical efficiency, many scholars have separated technical efficiency from TFP and used it as a measure of economic efficiency. They argue that various aspects of human capital significantly enhance regional economic efficiency (Y. Luo & Li, 2023; X. Wang et al., 2023). While overall public expenditure may reduce regional economic efficiency, targeted spending on general public services, education, and agriculture, forestry, and water affairs has a positive impact on improving regional economic efficiency (Li et al., 2016).

2.2. Research on the impact of financial development and reform on economic efficiency

The financial system plays a crucial role in guiding capital allocation, as capital is fundamental for producers to acquire production factors for their activities. Both internationally and domestically, it is widely agreed that financial development and availability enhance investment or capital allocation efficiency, which in turn boosts the real economy (Naeem & Li, 2019; Wurgler, 2000). This improvement in capital allocation efficiency further impacts overall economic efficiency. Numerous domestic and international studies have highlighted that financial development and reform significantly impact economic efficiency, with effects varying according to the stage of regional development. For example, financial openness has been shown to have a significant positive effect on TFP in underdeveloped economies, such as many developing countries in Africa (Okunade, 2022). In contrast, financial market reforms have been crucial for productivity growth in rapidly growing economies with high potential, such as the BRICS nations (Rehman & Islam, 2022).

In China, the scale and composition of financial development are particularly important for enhancing provincial economic efficiency (R. Liu et al., 2022). Additionally, recent research suggests that financial reform measures, such as the rationalization of interest rate marketization, can be a key driver of economic efficiency (Tan et al., 2016). Furthermore, the geographical distance between financial institutions and producers also affects enterprise productivity to varying degrees (X. Wang et al., 2018).

2.3. Research on the relationship between digital financial inclusion and economic efficiency

Financial inclusion refers to the provision of appropriate and effective financial services at affordable costs to all social strata and groups in need, based on principles of equal opportunity and commercial sustainability. As a government-backed financial reform measure focusing on fairness, financial inclusion can drive economic growth when it reaches a sufficient scale (Y. Liu et al., 2021). It impacts economic activities across various sectors, including households and manufacturers, by addressing factors such as income distribution disparities and improvements in education levels (Y. Yang & Fu, 2019). Given the factors influencing economic efficiency discussed above, financial inclusion can have diverse effects on economic activities and, consequently, on overall economic efficiency. In international contexts, financial inclusion is also a crucial strategy for alleviating poverty and fostering economic development.

(Rojas Cama & Emara, 2022) use the manufacturing industries data of eleven MENA countries and twelve emerging markets (EMs) as their research samples. Using a sectoral analysis, they argue that financial inclusion improves the allocation of resources across small and medium firms, and has a positive, statistically significant effect on the size of gross capital formation in the low R&D-intensity industries. (Emara & El Said, 2021)) use data from developing regions such as the MENA countries as a sample. Their study find that financial inclusion effectively promotes economic growth, especially in countries with relatively low levels of financial access services, and this effect is established in the case of effective governance. (Ahmad et al., 2023) use panel data of 146 countries to study the impact of mobile money on financial inclusion and economic growth, and find that mobile money promoted economic growth by improving financial inclusion. (Siddiki & Bala-Keffi, 2024) revisits the relationship between financial inclusion and economic growth by taking 153 countries as research samples, and argue that while financial inclusion consistently correlates with economic growth, the magnitude and impact of this relationship vary between countries at different levels of financial development

The Matthew Effect is a notable characteristic of the Internet, with some studies suggesting that while the Internet fosters technological progress in China, it may simultaneously inhibit technical efficiency (T. Li et al., 2020). However, digital financial inclusion, which merges digital technology with financial inclusion, not only mitigates the Matthew Effect but also enhances the inclusivity of traditional financial services by leveraging the Internet's characteristics. This combination produces a range of more complex effects. As a tool for broadening financial services and advancing financial development, digital financial inclusion enhances financial availability in underserved areas, such as rural regions, and offers benefits such as promoting entrepreneurship and increasing income (Y. Zhang & Xie, 2019). Unlike the target population of traditional finance, this innovative approach focuses on alleviating financial constraints for key groups on the demand side, potentially improving financial availability and subsequently impacting regional economic efficiency. Digital financial inclusion has been shown to reshape the allocation of financial resources, effectively enhancing capital allocation efficiency and improving financial service efficiency in the real economy (D. Luo et al., 2022). Based on its 'digital' characteristics, some scholars argue that digital financial inclusion acts as a form of fintech that can significantly boost provincial TFP by fostering innovation and technology spillovers (Chen et al., 2022). Additionally, it lowers financial barriers and improves regional TFP, with these effects becoming more pronounced when regional carbon emissions are reduced (R. Liu et al., 2022). Digital financial inclusion also

exhibits spatial spillover effects (Wen & Shao, 2025)

2.4.Summary of literature

The literature reviewed reveals the following key insights: First, regional economic efficiency can be assessed from two perspectives: total productivity and factor productivity. This paper adopts the former, viewing regional economic efficiency as the input-output conversion efficiency of a region, to be measured by technical efficiency. While factor productivity measures may offer greater precision, they are less effective in capturing the efficiency conversion ratio. Second, the primary factors affecting regional economic efficiency include resource allocation, innovation, openness to external markets, human capital, and government transfer payments. Third, finance is closely linked to regional economic efficiency. Financial development play crucial role in early-stage regional development and financial reform will become the main driving force at advanced development stages. Fourth, financial inclusion enhances capital formation and economic growth by addressing gaps in financial supply for underserved groups. Digital financial inclusion, in particular, has different degrees of promoting effect on the efficiency of various aspects in regional economic development and can improve regional economic efficiency through multiple channels.

3. Theoretical analysis and research hypothesis

Digital financial inclusion enhances regional economic efficiency primarily through two channels, as illustrated in Figure 1. The first channel involves the direct impact on the allocation efficiency of production factors prior to production, which will be discussed in the first two sections of this chapter. The second channel concerns the indirect impact on the efficiency of producers during production processes, detailed in Section 3.

3.1.Direct effect and mechanism of digital financial inclusion on regional economic efficiency

Digital financial inclusion begins with the concept of 'inclusion,' while its digital aspect provides a distinctive feature that transforms it into a tool independently utilized by the demand side. This makes digital financial inclusion timely, accurate, and effective, extending its reach to most economic producers in the digital economy era. Consequently, this paper investigates the relationship between digital financial inclusion and regional economic efficiency,

considering digital financial inclusion as a means of promoting 'fairness.' The trade-off between efficiency and fairness is a fundamental issue in the socialist market economic system, and it is essential to manage their relationship effectively. The stage of high-quality development emphasizes both speed and quality, representing a combination of efficiency and equity (Changfu & Miaomiao, 2023). This stage promotes efficiency through equity (Zheng & Wu, 2024). In the early stages of economic development, production factors naturally seek higher returns and tend to concentrate in regions with endowment advantages, leading to increased economic efficiency and growth. According to the theory of cyclic cumulative causality, regions with natural endowment advantages tend to attract production factors from surrounding areas, exacerbating regional inequality through the 'backwash effect.' As economic development progresses, production factors become excessively agglomerated in developed regions, leading to higher costs and diminishing returns, which triggers a 'spread effect' to less developed areas. If government fiscal expenditure remains within a reasonable range, it can promote regional economic growth and enhance the 'spread effect,' thereby achieving a balance between equity and efficiency (Hu et al., 2023). Excessive agglomeration may lead to heightened competition. From an economic welfare perspective, competition is not always beneficial and intense competition can reduce economic efficiency and welfare (Cao, 2008). Digital financial inclusion, as a tool inherently oriented towards 'fairness,' influences regional economic efficiency by improving the availability of factors in financially vulnerable regions and groups. The driving force for the improvement of regional economic efficiency comes from the production transformation efficiency of input factors and output factors. It is driven by two key factors: the allocation efficiency of production factors prior to production and the efficiency of producers during production processes. The direct effect of digital financial inclusion pertains to the first factor, which is improving the effectiveness of factor allocation prior to production. Given certain production inputs, producers must effectively combine and utilize these inputs to generate economic output. In this process, financial resources support producers by enabling them to purchase and utilize production factors, facilitating capital turnover and acquiring the desired factors to maximize output value. As China’s economic growth has reached a new stage, 'spread effect' is becoming evident (Mao et al., 2022). Digital financial inclusion can enhance the spread of production factors by easing financial constraints in vulnerable regions and among disadvantaged groups. This enables these regions and groups to allocate production factors more freely, improving their scale benefits, bringing production efficiency closer to the optimal frontier, and thus enhancing overall regional economic efficiency.

To examine this impact mechanism of digital financial inclusion, this paper uses the level of transportation infrastructure as a moderating variable. Transportation infrastructure serves as a crucial carrier for the flow of production factors. Labor and capital, as key production factors, are ible and require physical carriers for their movement. Digital financial inclusion can enhance the economic efficiency of vulnerable groups and regions within a province through the allocation efficiency of production factors, thereby improving overall provincial economic efficiency. This improvement can be further supported by the development of transportation infrastructure. Based on this, the paper proposes Hypothesis 1.

Hypothesis 1: Digital financial inclusion can promote regional economic efficiency, and this effect is amplified by improved factor mobility facilitated through well- developed transportation infrastructure. The role of financial development in enhancing the efficiency of the real economy is widely acknowledged, yet opinions differ on the impact of traditional financial development on regional economic efficiency. (C. Li & Li, 2023) argue that financial development significantly boosts the overall improvement of provincial TFP. Conversely, other studies suggest that the current banking system development model often hinders economic efficiency (Xu et al., 2019), and that financial development may not necessarily enhance technical efficiency (Zhong & Li, 2020).

There is limited research on the relationship between digital financial inclusion and traditional finance concerning regional economic efficiency. This paper argues that the fundamental purpose of finance is to facilitate the financing of production resources for economic producers. Driven by profit motives, finance tends to gravitate towards developed regions with high production efficiency, creating backwash effect. In cases where developed regions attract production factors from surrounding areas, finance amplifies this effect, increasing factor agglomeration. Consequently, developed regions in provinces with advanced financial systems are better positioned to attract a substantial amount of production factors. When digital financial inclusion alleviates financial constraints in vulnerable areas and among disadvantaged groups, these regions can more readily access production factors, achieve improved production outcomes more swiftly, and generate scale effects that enhance economic efficiency. However, the strong provincial borders impede the flow of production factors. In provinces with underdeveloped financial systems, disadvantaged areas and groups face greater challenges in accessing production factors compared to those in provinces with advanced financial development. Allocating production factors to less developed regions and groups may not enhance overall regional economic efficiency. Instead, it is more effective to direct limited resources to developed areas and highly efficient groups within such provinces. Based on this,

the paper proposes Hypothesis 2.

Hypothesis 2: In provincial regions with more advanced traditional financial development, digital financial inclusion plays a greater role in enhancing regional economic efficiency.

3.2. Effect differences of digital financial inclusion on regional economic efficiency under heterogeneity

The effectiveness of digital financial inclusion in enhancing regional economic efficiency is grounded in addressing the efficiency loss associated with excessive factor agglomeration within the region. Excessive agglomeration typically occurs in highly developed economic areas. Given China's current economic imbalance, with varying levels of development across its four major macro-regions, the impact of digital financial inclusion may yield different results in each region. According to the hypothesis proposed, traditional finance and digital financial inclusion are generally complementary. Traditional finance primarily supports production in developed regions and advantageous groups, while digital financial inclusion aids vulnerable regions and groups, with both mutually reinforcing each other (X. Wang & Fu, 2021). However, the 'digital' nature of digital financial inclusion and its demand-side characteristics may lead to the Matthew effect (Frost et al., 2020). In provinces with underdeveloped traditional finance, digital financial inclusion may primarily benefit developed regions and groups, serving as a supplement to traditional finance. This can create backwash effect, potentially diminishing its impact on improving regional economic efficiency. Based on this, the paper proposes Hypothesis 3.

Hypothesis 3: The effectiveness of digital financial inclusion in enhancing regional economic efficiency depends on the existing economic foundation and the level of development of traditional finance.

3.3. Indirect effect and mechanism of digital financial inclusion on regional economic efficiency

As discussed, the improvement in regional economic efficiency is driven by two key factors. Digital financial inclusion enhances another aspect of regional economic efficiency: the efficiency of the production process. Increased entrepreneurial activity fosters the diverse use of production factors, aiding traditional sectors in undergoing multi-level transformations (Fang, 2023). This shift impacts economic development structures, stimulates emerging industries, promotes the formation of new sectors and business models (T, 2021), and ultimately raises the overall efficiency of regional economic producers. As an innovative demand-side financial tool, digital financial inclusion significantly impacts ordinary people's

entrepreneurship by providing crucial financial support for entrepreneurial activities. On the other hand, within the production process, when technical conditions and input factors remain constant, an increase in the quality of input factors leads to higher output, thereby improving production efficiency. Although strong provincial boundaries impede the inter-provincial flow of production factors, digital financial inclusion can effectively enhance the quality of input factors within a province. Investment in educational human capital in provinces with lower economic development levels can improve technical efficiency through a catch-up effect. Digital financial inclusion can support household investment in education, promote the equalization of educational opportunities (Tay et al., 2022), and enhance regional economic efficiency by reducing educational inequality between provinces. Based on this, the paper proposes Hypothesis 4.

Hypothesis 4: Digital financial inclusion can promote regional economic efficiency by fostering entrepreneurial activities and reducing educational disparities between regions.

4. Data source, variable selection and model setting

4.1.Data sources

The data used in this paper comes from two sources. (1) The provincial-level China Digital Financial Inclusion Development Index data is compiled by the Digital Finance Research Center of Peking University and Ant Financial Services Group (Guo et al., 2020). (2) The provincial-level economic data comes from the database of China Economic Network, China Statistical Yearbooks and statistical yearbooks of various provinces and cities. This paper uses panel data from 30 provinces in China covering the period from 2011 to 2020. There are two main reasons for selecting this time frame. First, due to data limitations, the digital financial inclusion data provided by Peking University is available only for the years 2011 to 2020. Second, this period marks significant advancements in China's financial inclusion and digital finance, as well as the country's transition to a new era of economic transformation. Consequently, this time frame is particularly relevant for the research. To sum up, the data in this paper are the panel data of 30 provinces from 2011 to 2020 (Tibet is not included in the statistics due to serious lack of data). During the investigation period, some missing values are filled up by interpolation and linear fitting.

4.2.Variable selection

4.2.1. Dependent variables

The dependent variables in this paper are regional Economic efficiency (TE). TFP, commonly used to measure regional economic efficiency, is typically decomposed into three components: technical efficiency, technical progress, and allocative efficiency. Technical efficiency assesses the minimum input required for a given output or the maximum output achievable with a given input. It reflects the input-output conversion ratio under specific technological conditions. Technical progress, on the other hand, examines changes in TFP over time and represents improvements in technical conditions beyond just technical efficiency. Allocative efficiency pertains to the relative prices of input factors and is measured by the degree of deviation between output elasticity and cost share, with greater efficiency indicated by closer alignment between the two. This component focuses on the relationship between factor allocation across regions and associated costs. This paper investigates how digital financial inclusion, as a 'fair' mechanism, reshapes the provincial allocation system of factors through financial means, bringing producers closer to the production frontier under existing technology and thereby improving production efficiency. Consequently, the research focuses solely on the impact of digital financial inclusion on technical efficiency, rather than on technological progress or cross-provincial allocative efficiency. To clarify the impact mechanism of digital financial inclusion, this paper excludes the effects of technological progress and allocative efficiency from the analysis, concentrating instead on technical efficiency as a measure of production efficiency.

This paper uses Stochastic Frontier Approach (SFA) to measure regional economic efficiency. Compared with Data Envelopment Analysis (DEA), SFA decomposes the error term of the production function into random disturbance term and technical inefficiency term. Therefore, SFA can better describe the behavior of producers when there is a significant correlation between random factors and errors. Regarding the form of the production function, the trans-log production function is used in this paper. Referring to the model setting method of (Battese & Coelli, 1995), the specific functional form is as follows:

$$lnY_{it}=\beta_0+\beta_1 lnL_{it}+\beta_2 lnK_{it}+\beta_3 t+0.5\beta_4(lnL_{it})^2+0.5\beta_5(lnK_{it})^2+0.5\beta_6 t^2+$$
$$\beta_7 lnL_{it}lnK_{it}+\beta_8 tlnL_{it}+\beta_9 tlnK_{it}+v_{it}-u_{it}\quad TE_{it}=exp(-u_{it}) \quad (1)$$

In Equation (1), i and t represent province and period respectively. Y, L and K respectively represent the GDP of the region, the number of employees in the whole society and the stock of fixed capital investment, which are all standardized. β is the parameter to be estimated.

v_{it} is the random disturbance term which follows a normal distribution. u_{it} is the technical inefficiency term which follows a non-negative truncated normal distribution. TE is technical efficiency which can be estimated by the production function of the above form. Measure indicators include: (1) Output indicator: The output indicator in this paper is the regional GDP, which is standardized with the base period of 1992. (2) Input indicators: This paper adopts two input indicators, namely capital stock (K) and labor input (L), both of which belong to physical flow factors in terms of factor allocation. The capital stock (K) is calculated using the perpetual inventory method. Under this approach, the longer the estimation period, the less the impact of the base period data on the study. This paper takes 1992 as the base period, because it is in 1992 that China first clearly proposes the goal model of establishing a socialist market economic system. Since then, China's economic development has been in a brand new institutional environment. At the same time, the use of 1992 as the base period ensures that the impact of the base year data is fully attenuated between 1992 and 2010. The specific calculation formula is as follows:

$$K_t = {}^{I_t}/_{P_t} + (1-\delta)K_{t-1} \quad (2)$$

In Equation (2), K_t is the fixed capital stock of the province in period t. K_{t-1} is the fixed capital stock of provinces in period t-1. δ is the depreciation rate. I_t is the total fixed capital investment of the province in period t. P_t is the fixed capital investment price index of provinces in period t. The total amount of fixed capital investment adopts the index of fixed capital investment of the whole society in the statistical yearbook. As the indicator released to 2017, 2018-2020 data is calculated by its growth rate. The missing value of fixed capital investment price index is calculated by referring to the method of (J. Zhang, 2008) through the investment implicit deflator with 1992 as the base period. The price index of fixed capital investment in 2020 refers to the method of (Xiao et al., 2022), which is obtained by averaging the price index of fixed capital investment in 2018 and 2019. The depreciation rate is set at 9.6% according to (J. Zhang, 2008), and the fixed capital stock in the base period is obtained by dividing the total fixed capital investment in 1992 by 10% according to (J. Zhang, 2008). Labor input (L) is measured by the number of employed people in the whole society at the end of each year in the province.

4.2.2. Independent variables

The independent variable of this paper is Digital Financial Inclusion Index (DFII), which selects the Peking University Digital Financial Inclusion Index released by Peking University from 2011 to 2020. The provincial level digital financial inclusion index is adopted to

measure the development degree of digital financial inclusion in Chinese provinces. The index constructs a digital financial inclusion index system from three dimensions: the coverage breadth, the depth of digital finance use and the digitalization degree of financial inclusion. To be specific, the current digital financial inclusion Index contains 33 specific indicators in the three dimensions mentioned above. (See Appendix 1 for the specific explanation of each indicator of the digital financial inclusion index and the index synthesis method). Control variables After referring to relevant literature which studies the factors affecting regional economic efficiency, this paper selects the following control variables: Regional economic development (ED), Human capital (Edu), Openness to the outside world (Trade), Urbanization (Urban), Regional financial development (Fin), Fiscal expenditure (Fe), Industrial structure (Struc), Transport infrastructure (Infra). Specifically, the rising level of Regional economic development (ED) is an important feature of the improvement of economic efficiency, which is measured by the logarithm of regional GDP per capita in case of 1992 as the base period. Human capital (Edu) is the basic way for production organizers and labor to obtain relevant knowledge, and the improvement of economic efficiency is inseparable from the support of relevant knowledge, which is measured by the average education level of the population aged 6 and above. The degree of Openness to the outside world (Trade) can attract and use the advanced production management technology experience of foreign capital to improve the level of modernization and affect economic efficiency, which is measured by the proportion of import and export trade volume in GDP in the current year. Regions with high level of Urbanization (Urban) will gather a large number of production factors, affecting economic efficiency, which is measured by the proportion of urban resident population in the total permanent resident population. Regions with high levels of Regional financial development (Fin) guide the agglomeration of more production factors through financial means, affecting economic efficiency, which is measured by the proportion of the total balance of deposits and loans of financial institutions in GDP at the end of the year. Fiscal expenditure (Fe) is an important means of government intervention in economic development, and top-down intervention policy will have an impact on economic efficiency, measured by the proportion of general public budget expenditure in GDP. The change of Industrial structure (Struc) makes production factors flow between inefficient sectors and efficient sectors, affecting economic efficiency, which is measured by the proportion of the added value of the secondary and tertiary industries in GDP. The level of Transport infrastructure (Infra) is the basis of the flow of production factors and affects the economic efficiency, which is measured by the proportion of the sum of railway mileage,

highway mileage and inland river navigation mileage in the regional land area. The specific measurement and descriptive analysis of each indicator are presented in Table 1. Due to the need of heterogeneity analysis below, the descriptive analysis of some variables in the eastern, central and western regions is added.

Table 1 Descriptive statistics and description of variables

Variables	Mean	Std. Dev.	Min	Max	Variable specification
TE	0.4645	0.1861	0.2214	0.9953	The output factor corresponds to the regional GDP, while the input factors encompass both the capital stock and the number of employed people.
DFII	2.1725	0.9697	0.1833	4.3193	DFII/100
ED	10.7622	0.4191	9.6818	11.8531	GDP per capita (logarithm) with 1992 as the base period
Edu	9.2445	0.8800	7.51	12.68	Average level of education of population aged 6 and above (year/person)
Trade	0.0424	0.0453	0.0011	0.2266	Total import and export trade volume /GDP
Urban	0.5887	0.1233	0.3503	0.9377	Urban resident population/Total resident population
Fin	3.2921	1.0133	1.6776	7.2932	Balance of deposits and loans of financial institutions at the end of the year /GDP
Fe	0.2644	0.1145	0.1196	0.7583	General public budget expenditure /GDP
Struc	1.3245	0.7287	0.5271	5.2440	Added value of secondary and tertiary industries /GDP
Infra	1.0104	0.5593	0.7416	0.9972	(Railway mileage + highway mileage + inland river navigation mileage)/land area
Eastern ED	11.1021	0.3925	10.2405	11.8531	GDP per capita (logarithm) with 1992 as the base period
Central ED	10.6171	0.2538	10.0094	11.1207	GDP per capita (logarithm) with 1992 as the base period
Western ED	10.5080	0.3130	9.6818	11.1645	GDP per capita (logarithm) with 1992 as the base period
Eastern Infra	1.3496	0.4707	0.6805	2.5290	(Railway mileage + highway mileage + inland river navigation mileage)/land area
Central Infra	0.9294	0.4806	0.1459	1.7660	(Railway mileage + highway mileage + inland river navigation mileage)/land area
Western Infra	0.6859	0.5162	0.0921	2.2755	(Railway mileage + highway mileage + inland river navigation mileage)/land area
Eastern Fin	3.7520	1.2736	2.0869	7.2932	Balance of deposits and loans of financial institutions at the end of the year /GDP
Central Fin	2.7111	0.6038	1.6776	4.2356	Balance of deposits and loans of financial institutions at the end of the year /GDP

Western Fin	3.3758	0.6398	2.5501	5.0725	Balance of deposits and loans of financial institutions at the end of the year /GDP

5. Model setting

Based on the Hausman test, the benchmark regression in this paper adopts the two- way fixed effect model, and the specific form is as follows:

$$TE_{it}=\beta_0+\beta_1 DFII_{it}+\beta_2 *Controls_{it}+\theta_{it}+\mu_{it}+\varepsilon_{it} \quad (3)$$

In Equation (3), i and t are provinces and years respectively. Controls represent all control variables. θ_{it} and μ_{it} are individual fixed effects and year fixed effects, respectively, and ε_{it} is a random disturbance term.

6. Empirical results and analysis

6.1. Full sample benchmark regression

Table 2 shows the regression results of digital financial inclusion and regional economic efficiency. (1) to (2) are the regression results of the total index of digital financial inclusion on regional economic efficiency, and (3) to (5) are the regression results of the breadth of coverage (BC), depth of use (DU) and degree of digitalization (DD) respectively, and they are the three dimensions of digital financial inclusion. With the addition of control variables, R square gradually becomes larger, which indicates that the explanatory power of the model is enhanced, so we mainly focus on columns (2) to (5)

Table 2 Regression results of the impact of digital financial inclusion on regional economic efficiency

	Regional economic efficiency (TE)				
Independent variables	（1）	（2）	（3）	（4）	（5）
DFII	0.0240***	0.0141***			
	（8.83）	（6.17）			
BC			0.0106***		
			（3.07）		
DU				0.0070***	
				（5.35）	
DD					0.0038***
					（4.44）
ED		0.0089*	0.0132**	0.0130**	0.0107**
		（1.7）	（2.43）	（2.49）	（1.97）
Edu		0.0031***	0.0029***	0.0028***	0.0032***
		（2.99）	（2.67）	（2.63）	（3）
Trade		-0.0529***	-0.0669***	-0.0599***	-0.0660***

		（-3.09）	（-3.74）	（-3.47）	（-3.79）
Urban		-0.0640***	-0.0863***	-0.0582***	-0.0612***
		（-5.19）	（-6.49）	（-4.53）	（-4.7）
Fin		-0.0013	-0.0013	-0.0019*	-0.0013
		（-1.58）	（-1.45）	（-2.21）	（-1.43）
Fe		-0.0024	-0.0034	-0.0005	-0.0054
		（-0.28）	（-0.37）	（-0.06）	（-0.6）
Struc		0.0063***	0.0063***	0.0065***	0.0070***
		（4.27）	（4.07）	（4.38）	（4.61）
Infra		-0.0057***	-0.0047**	-0.0051**	-0.0045*
		（-2.44）	（-1.92）	（-2.15）	（-1.88）
Year and region fixed effects	Fixed	Fixed	Fixed	Fixed	Fixed
Observations	300	300	300	300	300
R^2	0.2307	0.5756	0.5291	0.5613	0.5469

Note: ***, ** and * indicate significance at the levels of 1%, 5% and 10%, respectively, and the t-values are in parentheses.

In Column (2), digital financial inclusion shows a significant positive impact on regional economic efficiency at the 1% confidence level. This finding indicates that the development of digital financial inclusion has effectively enhanced regional economic efficiency. The subsequent analysis will explore the direct mechanisms underlying this influence. Existing research primarily investigates the effect of digital financial inclusion on regional TFP across various levels, generally concluding a positive relationship between the two. Compared to existing research, this paper empirically finds that digital financial inclusion significantly promotes regional economic efficiency characterized by technical efficiency. However, the underlying mechanisms differ from those commonly discussed in the literature. Existing studies often attribute the impact of digital financial inclusion to factors such as innovation, technology spillover, carbon emissions, industrial structure upgrading, household consumption, and technological progress (Chen et al., 2022; He MB & Yang XW, 2021; Y. Li et al., 2023). These mechanisms generally explain how digital financial inclusion promotes TFP through technological progress. In contrast, this paper highlights how digital financial inclusion addresses excessive agglomeration, reshapes regional labor division, and promotes economic efficiency from the perspective of production factor allocation.

The regression results for digital financial inclusion after dimension reduction, presented in columns (3) to (5), demonstrate that all three dimensions significantly enhance regional economic efficiency. Among these dimensions, coverage breadth has the most substantial effect. A broader coverage of digital financial inclusion facilitates the spread of production factors, thereby improving the effectiveness of production factor allocation across the entire

provincial region.

Regarding control variables, higher levels of regional economic development and human capital, as well as a greater proportion of secondary and tertiary industries in the industrial structure, are associated with improved regional economic efficiency. Conversely, the degree of openness to the outside world and the level of urbanization negatively impacts regional economic efficiency. This suggests that factor inputs in the region may have reached a saturation point, with excessive agglomeration of factors. As a result, increasing capital input alone is insufficient to boost economic efficiency, and higher urbanization levels may exacerbate factor agglomeration, potentially reducing efficiency. Additionally, the ineffectiveness of fiscal expenditure in enhancing regional economic efficiency indicates that top-down public expenditure interventions are not effective, highlighting the need to redesign intervention mechanisms to better balance equity and efficiency.

6.2.An analysis of the influencing mechanism by which digital financial inclusion directly impacts regional economic efficiency

To test Hypotheses 1 and 2, which posit that digital financial inclusion reshapes the factor allocation system within provinces through financial means, thereby bringing economic producers closer to the production frontier under existing technological conditions and improving production efficiency, as well as the relationship between traditional finance and digital financial inclusion in this process., this paper constructs two interaction terms. These are: (1) the interaction term between regional financial development and digital financial inclusion, and (2) the interaction term between transportation infrastructure and digital financial inclusion. These interaction terms are used to analyze the moderating effects of traditional financial development and transportation infrastructure on the regional economic efficiency driven by digital financial inclusion. The specific setup of the moderating effect model is as follows:

$$TE_{it}=\beta_0+\beta_1 DFII_{it}+\beta_2 Fin_{it}+\beta_3 DFII_{it} * Fin_{it}+\beta_4 *Controls_{it}+\theta_{it}+\mu_{it}+\varepsilon_{it} \quad (4)$$

$$TE_{it}=\beta_0+\beta_1 DFII_{it}+\beta_2 Infra_{it}+\beta_3 DFII_{it} * Infra_{it}+\beta_4 *Controls_{it}+\theta_{it}+\mu_{it}+\varepsilon_{it} \quad (5)$$

In Equations (4) and (5), Fin is regional financial development. Infra is transport infrastructure. $DFII_{it} * Fin_{it}$ and $DFII_{it} * Infra_{it}$ are the interaction terms of digital financial inclusion and the previous two. Regression analysis is performed using the constructed moderating effect model, with the results presented in Table 3. Column (1)

displays the regression results without moderating variables, while Columns (2) through (5) show the results incorporating moderating variables and interaction terms.

	Regional economic efficiency (TE)				
Independent variables	（1）	（2）	（3）	（4）	（5）
DFII	0.0136***	0.0134***	0.0098***	0.0143***	0.0011
	（5.94）	（5.84）	（4.08）	（6.25）	（0.41）
Fin		-0.0011	-0.0038***		
		（-1.3）	（-3.61）		
DFII*Fin			0.0009***		
			（4.11）		
Infra				-0.0053**	-0.0198***
				（-2.27）	（-7.2）
DFII*Infra					0.0028***
					（8.03）
Controls	Yes	Yes	Yes	Yes	Yes
Observations	300	300	300	300	300
R^2	0.5627	0.6565	0.5929	0.5714	0.6587

The results in Columns (4) and (5) indicate that the level of transportation infrastructure significantly impedes the improvement of regional economic efficiency at the 1% confidence level. This suggests that the backwash effect of production factors within a region outweighs the spread effect, and the latter has not effectively contributed to enhancing regional economic efficiency. Since production factors are predominantly physical flow factors with tangible substance, regions with better transportation infrastructure facilitate their movement, thereby concentrating these factors in areas with economic and financial advantages. Consequently, transportation infrastructure reinforces the backwash effect. However, excessive agglomeration has been difficult to effectively improve economic efficiency. Some research suggests that transportation infrastructure not only enhances TFP at the provincial and city levels (Ponomarev, 2022; H. Sun et al., 2024) but also exhibits spatial spillover effects (C. Li & Li, 2023). However, this paper focuses on regional economic efficiency as measured by technical efficiency, rather than TFP, under a different influence mechanism, leading to differing conclusions. The positive and significant interaction term indicates that digital financial inclusion has a more pronounced effect on improving economic efficiency in regions with better transportation infrastructure. This is because digital financial inclusion amplifies the spread effect and

enhances factor allocation efficiency by reshaping the allocation system of production factors. In regions with superior transportation infrastructure, digital financial inclusion more effectively redistributes production factors from advantaged areas and groups to those with less access but potential for improved economic efficiency, thereby further enhancing the spread effect and boosting overall regional economic efficiency. This supports Hypothesis 1.

The results in Columns (2) and (3) indicate that regional financial development alone does not significantly enhance regional economic efficiency, although the interaction term is positive and significant. This finding aligns with (Chekol et al., 2023), who observed that total credit scale has a limited impact on production technical efficiency, whereas private sector credit plays a significant role in improving technical efficiency. This suggests that traditional finance is no longer a major driver of regional economic efficiency. However, digital financial inclusion proves to be more effective in enhancing regional economic efficiency, particularly in regions with well-developed traditional financial systems. Thus, digital financial inclusion and traditional finance act as complementary mechanisms in improving regional economic efficiency. The observed phenomenon may be attributed to the fact that well-developed traditional finance tends to concentrate production factors in more developed regions and groups, leading to increased efficiency losses due to excessive agglomeration. Consequently, digital financial inclusion is more effective at improving factor allocation efficiency in such regions. Conversely, in areas with relatively underdeveloped traditional finance, the 'fair' characteristics of digital financial inclusion may impede the flow of factors to developed regions and groups that is more efficient in this case. Moreover, digital financial inclusion might also serve as a supplement to traditional finance in developed regions, thereby intensifying the backwash effect and diminishing overall economic efficiency. This supports Hypothesis 2.

6.3.The direct influence mechanism of digital financial inclusion on regional economic efficiency: heterogeneity analysis

To verify Hypothesis 3—that the effectiveness of digital financial inclusion in improving regional economic efficiency depends on a certain economic foundation and the level of traditional finance—this paper divides the sample regions into three groups: eastern, central, and western regions. The analysis is presented in Table 4 and Table 5. In Table 4, transport infrastructure is used as a moderator variable, and the regression is carried out after adding

interaction terms in the three regional groups.

Table 4 Heterogeneity analysis 1 of the impact of digital financial inclusion on regional economic efficiency

	Regional economic efficiency (TE)					
	Eastern regions		Central regions		Western regions	
Independent Variables	（1）	（2）	（3）	（4）	（5）	（6）
DFII	0.0249***	0.0059	0.0008*	0.0013**	-0.0005	-0.0005
	（3.73）	（1.01）	（1.77）	（2.61）	（-1.6）	（-1.57）
Infra	-0.0209**	-0.0240***	0.0097*	0.0108**	0.0021*	0.0020*
	（-2.05）	（-3）	（1.75）	（1.76）	（1.13）	（1.01）
DFII*Infra		0.0050***		-0.0002**		0.0001
		（7.19）		(-2.12)		（0.05）
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	110	110	100	100	90	90
R^2	0.6692	0.7991	0.1988	0.2467	0.7063	0.7129

Note: ***, ** and * indicate significance at the levels of 1%, 5% and 10%, respectively, and the t-values are in parentheses.

The regression results in Table 4 indicate that digital financial inclusion significantly enhances regional economic efficiency in the eastern region at the 1% confidence level. In the central region, while the effect of digital financial inclusion remains significant, both the confidence level and the coefficient have diminished considerably. In the western region, digital financial inclusion does not effectively impact regional economic efficiency. As shown in Table 1, the eastern region substantially outperforms both the central and western regions in terms of regional economic development, with the central region also exceeding the western region. This suggests that the effectiveness of digital financial inclusion in improving regional economic efficiency is dependent on a certain level of economic foundation. Table 1 shows that the mean value of transportation infrastructure in the eastern region is higher than in the central and western regions. In the eastern region, transportation infrastructure negatively impacts regional economic efficiency, whereas in the central and western regions, it has a positive effect. This further underscores that the improvement of regional economic efficiency through digital financial inclusion necessitates a certain level of economic development. When economic development reaches a certain level, a high concentration of factors in the production activities of advanced regions leads to efficiency losses. Consequently, while transportation infrastructure in developed areas may negatively impact efficiency, digital financial inclusion can enhance economic efficiency by amplifying the spread effect of production factors, as observed in the eastern region. The central and western regions, particularly the western region,

are relatively underdeveloped. When economic development has not reached a certain level, the scale of factor input in these regions is limited, and the scale and agglomeration effects of more developed regions with higher efficiency continue to grow. In this scenario, digital financial inclusion's allocation of factors to vulnerable areas and groups may diminish economic efficiency. Consequently, transportation infrastructure plays a positive role in these regions, as it facilitates the concentration of factors in high-efficiency areas, thereby enhancing overall regional economic efficiency.

The interaction term analysis reveals that transportation infrastructure positively moderates the effect of digital financial inclusion in the eastern region, negatively moderates it in the central region, and shows no significant effect in the western region. This indicates that the effectiveness of digital financial inclusion in improving regional economic efficiency is contingent upon a robust economic foundation that supports factor agglomeration. Otherwise, the Matthew effect of digital financial inclusion may lead to the opposite or no effect of good transportation infrastructure on the moderation of digital financial inclusion. Thus, digital financial inclusion reflects both fairness and efficiency in enhancing economic efficiency in the eastern region. Overall, not only highlights the unity of fairness and efficiency, but also shows the contradiction between them. In Table 5, regional financial development is used as a moderator variable, and the regression is carried out after the interaction term is added to the three regional groups.

Table 5 Heterogeneity analysis 2 of the impact of digital financial inclusion on regional economic efficiency

	Regional economic efficiency (TE)					
	Eastern	regions	Central regions		Western	regions
Independent variables	（1）	（2）	（3）	（4）	（5）	（6）
DFII	0.0249***	0.0313***	0.0008*	0.0009*	-0.0005	-0.0004
	（3.73）	（4.21）	（1.77）	（1.96）	（-1.6）	（-1.24）
Fin	-0.0001	-0.0021	0.0181*	0.189*	0.0223**	0.0230**
	（-0.01）	（-0.83）	（2.95）	（3.1）	（3.61）	（3.69）
DFII*Fin		-0.0012*		-0.0001		-0.0001*
		（-1.85）		（-1.2）		（-1.69）
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	110	110	100	100	90	90
R^2	0.6692	0.6828	0.1988	0.2148	0.7063	0.7192

Note: ***, ** and * indicate significance at the levels of 1%, 5% and 10%, respectively, and the t-values are in parentheses.

The regression results in Table 5 indicate that regional financial development significantly enhances economic efficiency in the central and western regions. The reason may be that

the improvement of economic efficiency in the central and western regions depends on the agglomeration and scale effect generated by developed regions and groups, and the financial development accelerates this factor agglomeration. The interaction term analysis reveals that, in the eastern and western regions, better financial development diminishes the role of digital financial inclusion in promoting regional economic efficiency. In contrast, the moderating effect of financial development on digital financial inclusion in the central region is not significant. From the mean values of regional financial development shown in Table 1, it is evident that financial development in the eastern and western regions significantly surpasses that in the central region. This suggests that while digital financial inclusion and traditional finance are generally complementary and mutually reinforcing, advanced levels of traditional finance can also lead to a spread effect, that is, financial resources begin to spread to vulnerable areas and groups. Although financial development does not significantly promote regional economic efficiency in the eastern region, this spread effect of financial resources does weaken the amplification effect of digital financial inclusion on the spread effect, and there is a substitution relationship between the two in this case.

Overall, the effectiveness of digital financial inclusion in enhancing regional economic efficiency depends on the level of economic development and traditional finance. In provinces with advanced economic development, there are more production factors available, which facilitates agglomeration in certain regions and groups, especially with the aid of transportation infrastructure. Additionally, as traditional finance accelerates this agglomeration process, digital financial inclusion can effectively improve regional economic efficiency by reallocating factors. This supports Hypothesis 3.

6.4.Robustness test and endogeneity analysis

To test the robustness of the model and regression results, we employ several methods. First, we winsorize all continuous variables in the data sample at the 1% level. Second, given that the dependent variable in this paper ranges between 0 and 1, we use a panel Tobit model for the replacement regression. Lastly, we replace the translog production function with the Cobb-Douglas production function and use Stochastic Frontier Analysis (SFA) to estimate technical efficiency. The results, presented in Table 6, show that the direction and significance of the coefficients remain consistent with the benchmark regression. This confirms the robustness of our conclusions.

Table 6 Robust test

	Regional economic efficiency (TE)					
	Winsorization		Tobit model		Replacement of the dependent variable	
Independent variables	（1）	（2）	（3）	（4）	（5）	（6）
DFII	0.0199***	0.0120***	0.0240***	0.0141***	0.0278***	0.0212***
	（6.47）	（4.61）	（9.49）	（6.74）	（25.35）	（8.94）
DFII	No	Yes	No	Yes	No	Yes
Year and region fixed effects	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Observations	300	300	300	300	300	300

Note: ***, ** and * indicate significance at the levels of 1%, 5% and 10%, respectively, and the values are in parentheses.

Regarding endogeneity analysis, this paper addresses two main concerns. First, we consider the potential estimation error from omitted variables, such as macroeconomic factors like cultural customs, which might influence the results. Second, we acknowledge the possibility of a bidirectional causal relationship between digital financial inclusion and regional economic efficiency. Specifically, the data for digital financial inclusion in this study come from Alipay, a third-party payment platform that integrates mobile payments with various financial services. Alipay enhances the convenience of daily life and work. Residents in regions with higher economic efficiency might experience a more accelerated lifestyle and are therefore more likely to use platforms like Alipay. This introduces the possibility of reverse causality, where improved economic efficiency could drive greater adoption of digital financial services. Additionally, this paper employs the Hausman test to assess whether digital financial inclusion is an endogenous variable. The test results reject the null hypothesis at the 1% significance level, indicating that digital financial inclusion is indeed endogenous. To address this endogeneity, we follow the method of (X. Wang & Fu, 2021) and construct an instrumental variable. This instrument is the product of the first-order lagged digital financial inclusion index and the first-order difference in time of the digital financial inclusion index. We then use this instrumental variable in an IV-2SLS regression to obtain robust results. Additionally, regional economic efficiency exhibits persistence and

may be serially correlated. To address this, this paper follows the method of (Qian & Wang, 2022) and employs system GMM regression to handle endogeneity, thereby enhancing the robustness of the conclusions. The results of the instrumental variable regression and system GMM regression are presented in Table 7.

Table 7 Endogeneity test

	The first stage of instrumental variable estimation	The second stage of instrumental variable estimation	System GMM
	Digital financial inclusion index (DFII)	Regional economic efficiency (TE)	Regional economic efficiency (TE)
Independent variables	（1）	（2）	（3）
DFII		0.0090**	0.0098**
		(1.93)	(2,21)
Instrumental variable	0.3481***		
	（12.16）		
L.TE			0.8899***
			（17.24）
Controls	YES	YES	YES
Year and region fixed effects	Fixed	Fixed	Fixed
Observations	300	300	270
R2	0.9963	0.9837	
Kleibergen-Paap rk LM statistic		38.18**	
Kleibergen-Paap rk Wald F statistic		147.92	
AR（1）			0.000
AR（2）			0.437
Hansen			0.149

Note: ***, ** and * indicate significance at the levels of 1%, 5% and 10%, respectively

The results from the instrumental variable regression in columns (1) and (2) show that the Kleibergen-Paap rk LM statistic significantly rejects the null hypothesis of instrumental variable under-identification at the 1% confidence level, indicating that the instrumental variables are correctly identified. The Kleibergen-Paap rk Wald F statistic is 147.92, well above the Stock-Yogo critical value of 16.38 at the 10% significance level, demonstrating that the selected instrumental variables are both reasonable and effective. In the first stage of the estimation, the instrumental variables are significantly positively correlated with digital financial inclusion. In the second stage, after controlling for endogeneity, digital financial inclusion continues to significantly enhance regional economic efficiency at the 5% confidence level, confirming the robustness of the results. The results from the system GMM regression in Column (3) indicate that AR(1) is significant at the 1% confidence level, while AR(2) is not significant. This suggests no autocorrelation in the model residuals, validating the use of system GMM. Additionally, the Hansen test p-value exceeds 0.1, confirming that the overidentification test passes and that the instrumental variable selection is appropriate. After accounting for the serial correlation characteristics of regional economic efficiency, digital financial inclusion continues to significantly enhance regional economic efficiency. This further substantiates the robustness of the paper's conclusions.

After accounting for the serial correlation characteristics of regional economic efficiency, digital financial inclusion continues to significantly enhance regional economic efficiency. This further substantiates the robustness of the paper's conclusions.

6.5.An analysis of the influencing mechanism by which digital financial inclusion indirectly impacts regional economic efficiency

Since the endogeneity problem in the mediating effect model cannot be adequately addressed, this paper follows the operational suggestion of (Qiu et al., 2024) by directly identifying the impact of digital financial inclusion on the mechanism variables. The influence of these mechanism variables on regional economic efficiency is then derived through theoretical analysis, supported by relevant literature. The enhancement of efficiency in the production process relies on both the activity of producers and the quality of input factors, specifically focusing on entrepreneurship and education levels as outlined in Hypothesis 4. To test this hypothesis, this paper selects two mechanism variables: entrepreneurial activity and

education gap. Entrepreneurial activity is measured by the ratio of the number of private and individual employees to the total number of employees at the end of the year. Education gap is assessed by the deviation in years of schooling per capita for the population aged 6 and above. The specific form of the regression model is as follows:

$$Mechanism_{it}=\beta_0+\beta_1 DFII_{it}+\beta_2 *Controls_{it}+\theta_{it}+\mu_{it}+\varepsilon_{it} \quad (6)$$

In Equations (6), $Mechanism_{it}$ represents the mechanism variables, namely, entrepreneurial activity and education gap. There may be endogeneity issues arising from measurement errors, omitted variables, and reverse causality between the dependent variables (entrepreneurial activity and education gap) and digital financial inclusion. There may be endogeneity issues arising from measurement errors, omitted variables, and reverse causality between the explained variables (entrepreneurial activity and education gap) and digital financial inclusion. To address these concerns, this paper uses he product of the first-order lagged digital financial inclusion index and the first-order difference in time of the digital financial inclusion index as the instrumental variable. IV-2SLS regression is employed to control for endogeneity. The regression results are shown in Table 8. Columns (1) and (3) are the test results using the two-way fixed effect model, and columns (2) and (4) are the test results using IV-2SLS.

Table 8 The mechanism of the indirect effect of digital financial inclusion on regional economic efficiency

	Mechanism variables			
	Entrepreneurial activity		**Education gap**	
	FE	IV	FE	IV
Independent Variables	（1）	（2）	（3）	（4）
DFII	0.2485***	0.1527*	-0.0045***	-0.0049**
	（5.2）	（1.71）	（-3.72）	（-2.41）
Controls Year and region fixed effects	YES	YES	YES	YES
Observations	300	300	300	300
R^2	0.4001	0.8317	0.9937	0.9949

Note: ***, ** and * indicate significance at the levels of 1%, 5% and 10%, respectively, and the t-values are in parentheses.

The results in Column (1) of Table 8 indicate that digital financial inclusion significantly enhances entrepreneurial activity. Column (2) confirms that, after controlling for endogeneity, digital financial inclusion still significantly promotes entrepreneurship at the 10% confidence level. This finding underscores that digital financial inclusion effectively supports entrepreneurs, leading to improvements in regional entrepreneurial activity. This, in turn, has a broad structural impact on economic development, thereby enhancing overall production efficiency in the region. Entrepreneurship is inherently high-risk, and securing loans from formal lending institutions can be challenging. The low barrier to entry provided by digital financial inclusion offers crucial financial support for entrepreneurial activities. This support stimulates entrepreneurial vitality, facilitates the spread of entrepreneurial ventures across various sectors, and fosters the emergence of new industries and business models. Consequently, this increased entrepreneurial activity improves the activity of producers in the production process across multiple industrial fields, thereby driving improvements in regional economic efficiency. (T, 2021) provide a theoretical analysis at multiple levels, demonstrating that entrepreneurial activity enhances economic development efficiency through empirical evidence. (Y. Sun & You, 2022) use the digital financial inclusion index from Peking University to investigate the impact of digital finance on urban economic efficiency and examine the mediating role of entrepreneurship using a mediating effect model. Their findings align with the conclusions of this paper, reinforcing the role of digital financial inclusion in boosting entrepreneurial activity and improving regional economic efficiency.

The results in Column (3) show that digital financial inclusion significantly reduces the educational gap between regions. Column (4), after controlling for endogeneity, confirms the robustness of this finding. This indicates that while the physical flow of production factors across provinces is often restricted, digital financial inclusion enhances the quality of existing input factors in a provincial region. Its 'digital' nature allows it to improve labor quality in provinces with less advanced education systems by narrowing the gap in per capita years of education between provinces. Consequently, this leads to increased output from the same level of input, thereby enhancing regional economic efficiency. Digital financial inclusion offers a balanced amount of financial support to vulnerable groups, particularly aiding laborers with lower education levels in accessing basic education, thus promoting educational equalization (Tay et al., 2022) and reducing the education gap. The narrowing of the educational gap implies that knowledge accumulation

occurs within groups with lower educational levels. The improvement in labor input quality depends on the enhancement of basic ability driven by knowledge accumulation. Knowledge accumulation can significantly improve basic ability of labor in various aspects. Specifically, the improvement of some aspects of basic ability improves their working ability. Basic education accelerates the 'learning by doing' process, enhancing workers' capabilities and thus improving the input-output ratio. (J. Liu & Bi, 2019) argue that reducing educational inequality contributes to TFP improvement. Although there is limited research on the role of education in the context of digital financial inclusion's impact on economic efficiency, the theoretical and empirical findings of this paper support the demonstrating that digital financial inclusion's role in narrowing educational gaps leads to better labor quality and, consequently, enhances regional economic efficiency.

7. Research conclusions and implications

The main research conclusions are as follows:

First, digital financial inclusion can significantly enhance regional economic efficiency, with the breadth of coverage being the primary influencing factor. This finding aligns with existing literature, yet it highlights a novel mechanism through which digital financial inclusion drives economic efficiency.

Second, in terms of the direct influence mechanism, transportation infrastructure and regional financial development enhance the effectiveness of digital financial inclusion in improving regional economic efficiency. This indicates that digital financial inclusion primarily boosts the economic efficiency of vulnerable groups and underdeveloped areas by enhancing the effectiveness of factor allocation within the region. Consequently, it contributes to overall regional economic efficiency, a process that can be supported by improvements in transportation infrastructure. Additionally, traditional finance and digital financial inclusion demonstrate a mutually reinforcing relationship.

Third, heterogeneity analysis reveals that the effectiveness of digital financial inclusion in improving regional economic efficiency is most pronounced in provinces with better economic and traditional financial development by improving the effectiveness of factor allocation within these provinces. This suggests that the impact of digital financial inclusion on regional economic efficiency is contingent upon a certain level of economic foundation and traditional

financial development. However, in the eastern and western regions, where traditional finance is more developed, a competitive alternative relationship exists between digital financial inclusion and traditional finance in enhancing regional economic efficiency.

Fourth, from the perspective of indirect influence mechanisms, digital financial inclusion enhances regional economic efficiency by boosting entrepreneurial activity and reducing the education gap. Specifically, entrepreneurship and educational improvement serve as crucial transmission channels through which digital financial inclusion exerts its impact.

7.1.These conclusions provide rich implications:

First, re-evaluating the role of digital financial inclusion in regional economic efficiency and different strategies are needed for provinces with varying development conditions. As a means of fairness, in the eastern and central regions, digital financial inclusion can achieve both fairness and efficiency, fostering equitable growth while also enhancing economic performance. However, in the western region, its impact is primarily limited to promoting fairness. To advance the high-quality development of the national economy, it is crucial to recognize these regional differences and tailor digital financial inclusion strategies accordingly to maximize their effectiveness. On this basis, we should leverage digital financial inclusion to optimize factor allocation in the eastern and central regions. For the central and western regions, it is essential to enhance factor input and drive economic development to improve overall economic efficiency.

Second, enhancing transportation infrastructure and accelerating the development of a unified national market are crucial for improving the free allocation of production factors across provinces. Effective factor allocation prior production is essential for regional economic efficiency, and achieving this requires eliminating administrative and physical barriers to factor flow. By addressing these barriers through improved infrastructure and market integration, we can strengthen the mechanisms that enhance regional economic efficiency.

Third, provinces should continue to advance the development of digital financial inclusion and enhance digital infrastructure. Currently, digital financial inclusion is strong in the east and south but weaker in the west and north. While digital financial inclusion significantly boosts economic efficiency in the eastern and central regions, its essential role is to enhance equity. At the same time, numerous studies suggest that digital financial inclusion can also

improve total factor productivity by fostering technological progress. Therefore, digital financial inclusion should also be vigorously developed in the relatively backward central and western regions to achieve comprehensive development in social equity, technical efficiency, technological progress, and total factor productivity. By improving digital infrastructure and fostering the growth of digital financial inclusion, we can better align equity with efficiency, addressing regional development imbalances while also enhancing overall efficiency.

Fourth, to better enhance regional economic efficiency, it is crucial to strengthen the integrated development of digital financial inclusion and traditional finance. Although digital financial inclusion and traditional finance generally complement each other in improving regional economic efficiency, there can be competitive or alternative relationship between the two in certain contexts. The government should carefully manage the interaction between traditional finance and digital financial inclusion, particularly in how financial resources are allocated to vulnerable groups and areas. Traditional financial institutions offer substantial financial resources, a wide range of products, and higher credibility. In contrast, digital financial inclusion provides timely, effective, and accessible financial resources. Therefore, it is essential to not only promote traditional financial services in financially vulnerable groups and areas but also to strengthen the expansion of digital financial inclusion and enhance digital literacy. This approach will prevent an over-reliance on one type of financial service as over-reliance could lead to a substitution effect between traditional and digital finance. Instead, it is necessary to foster the complementary advantages of digital financial inclusion and traditional finance and encourage their integrated development. This will generate synergy across all aspects of economic development in financially disadvantaged areas and groups, thereby fostering overall regional economic growth.

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