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Digital Economy Empowers the Development Efficiency Improvement Mechanism of Accessible Industries

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Abstract

The digital economy empowers the development efficiency of the accessible industry, which is crucial for its sustainable development. Previous studies have focused on a single part of the accessible industry, lacking an overall grasp of the industry. Furthermore, they have not yet elaborated on the driving role of the digital economy in the accessible industry. This paper constructs an index system for evaluating the development efficiency of the accessible industry empowered by the digital economy, and uses sample data from 31 provinces (cities) in China. By comprehensively employing the three-stage DEA model method, this paper explores the reasons for the differences in development efficiency among accessible industries, empirically analyzes their influencing factors and the mechanism of efficiency improvement, and fills the gap in research on the digital economy's impact on the accessible industry. The purpose is to deeply understand the development model of the accessible industry empowered by the digital economy through systematic evaluation and analysis, to accurately identify efficiency bottlenecks and clarify paths for improvement.

Keywords: digital economy; accessible industry; efficiency improvement mechanism; three-stage DEA model

1. Introduction

Accessible industry refers to a new type of business that provides the disabled, the elderly, and other groups with human function improvement compensation, replacement, or auxiliary treatment. At present, the degree of aging in China is deepening. According to the "national development bulletin on aging in 2024", China's aging population over the age of 60 was about 310 million, accounting for 22.0% of the total population, and the number of disabled people was also relatively large. According to the statistics of the China Disabled Persons' Federation, the number of disabled people who have received disability certificates reached 38.25 million. It can be seen that the number of the elderly and the disabled, as the main service objects of the accessible industry, will continue to expand, which will undoubtedly bring unprecedented opportunities and challenges to the development of the accessible industry. In addition, the promulgation and implementation of the law of the People's Republic of China on the construction of an accessible environment in 2023 marks the first time that the construction of an accessible environment has entered the national strategic layout, and the country's attention to the development of the accessible industry has reached a new height. In 2025, the promulgation of policies and regulations such as the notice on further strengthening the construction of urban accessible facilities will force the implementation of national standards in home, information, and other sectors, and also significantly enhance the reconstruction of the accessible industry.

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At the same time, after entering the "Fifteenth Five-Year Plan" period, digital technology has become a new engine for the country's high-quality development. Continuing to promote the in-depth development of the digital economy will help accelerate the construction process of Digital China. In the era of the digital economy, the iteration of digital technology can reshape the industrial organization mode and value orientation. With the acceleration of the new scientific and technological revolution and the promotion and application of information technologies such as big data and artificial intelligence, digital economy, as a new economic form, promotes the transformation of new industrial models and old and new kinetic energy with innovative technology, promotes the improvement of the social production mode and production efficiency, and plays a huge role in the development of enabling industries, which is expected to create opportunities and development conditions for the high-quality development of accessible industries in China.

However, at present, China has not yet formed a complete and sound accessible industry chain, and the relevant resources cannot be fully allocated effectively, which makes it difficult to meet the emerging service needs of the elderly and disabled groups. In addition, it is also facing problems such as unbalanced regional development, insufficient innovation ability, and low management efficiency, which make it difficult for the accessible industry to achieve high-quality development. Therefore, it is of practical significance to explore the efficiency level of the impact of the digital economy on the development of accessible industries, effectively improve development efficiency and competitiveness, help regions shorten the development gap, and provide targeted policy support for the development of regional digital economies and accessible industries. The specific objectives include combing the literature, focusing on the research subjects, elaborating the mechanism of improving the efficiency of accessible industries enabled by the digital economy, providing theoretical support, designing the model, analyzing the empirical results and discussing the efficiency improvement mechanism, and based on this information, putting forward suggestions on improving the efficiency of accessible industries [1].

2. Literature Review

2.1. Research on the Digital Economy

The digital economy is a kind of production factor that integrates data and knowledge, takes the modern Internet space as the scope of activities, and involves a wide range of business activities [2]. The related concepts were first proposed by Tepscott et al. [3]. have attracted great attention all over the world. With the rapid development and application of digital technology [4], scholars have carried out a lot of research, and the results mainly focus on the connotation, measurement, and economic effect of the digital economy. Among them, research institutions and scholars have carried out a series of discussions on the connotation of digital economy [5], and basically formed a consensus of "industrial digitalization" and "digital industrialization" [6]. As for the measurement of the digital economy, the evaluation system is mainly constructed from the dimensions of digital finance [7], industrial collaborative development [8], and industrial integration [9], and the entropy method and coupling coordination degree model are used to measure it [10]. As for the economic effect of the digital economy, it mainly focuses on the perspectives of enterprise technological innovation [11] and low-carbon emission reduction [12].

With further research, some scholars believe that the digital economy can enable the high-quality development of industry. For example, Fang et al. used the data of listed companies related to agriculture as samples to explore how the digital economy can promote the high-quality development of agriculture [13]. Chen et al. discussed the impact of the digital economy on the development of the manufacturing industry, and believed that the development of the digital economy would contribute to the balanced development of the

regional manufacturing industry [14]. Hou et al. constructed a two-way fixed effect regression framework and systematically elaborated the positive impact of the digital economy on the development of the elderly care industry [15]. Meng et al. and others discussed the impact of the digital economy on the development of the industrial green transformation through innovative empirical analysis models, and reached guiding conclusions [16].

2.2. Relevant Research on Accessible Design

At present, the research on accessible design mainly focuses on the development and application of BIM Technology, digital platform design, and artificial intelligence-aided design. In terms of the development and application of BIM Technology, Kang et al. have built an efficient, accessible (BF) certification evaluation [17] by implementing an information modeling system and combining the BIM evaluation template with IPA analysis. Newton et al. integrated BIM with facility management (FM), intended to be included in the post evaluation of accessible toilets [18]. In terms of digital platform design, Van et al. adopted a user-oriented, inclusive research method to build an inclusive digital research platform for individuals with mild intellectual disability and low literacy [19]. Costa et al. took Portugal as an example to develop a digital tourism platform for the actual accessibility needs of the elderly, and verified its effectiveness through extensive tests [20]. In terms of artificial intelligence-aided design, Dorri et al. proposed to enhance the customer-centric design method in accessible buildings through an AI-driven accessible VR platform based on smartphones and an intelligent support system (ISS) [21]. Guerrero et al. proposed a design method to evaluate universal accessible housing (UAH) through virtual reality simulation using artificial intelligence. Using this scientific design method, we can guide the development of an immersive virtual environment [22].

In order to further explore the impact of AI-aided design, scholars try to apply the deep learning and machine learning methods of AI to design concepts. For example, Zhang et al. used a deep learning method based on artificial intelligence to automatically generate symbols to break through the constraints of vector plane layout, and experiments have proved that this method is superior to the existing accessible design standard [23]. Cakiroglu et al. used BIM to simulate a double-deck terrace building in Malaysia, used an integrated machine learning model and genetic programming in the design, and analyzed and verified the feasibility and applicability of the method with Shap [24].

2.3. Research on Accessible Facilities and Products

In research on accessible facilities, scholars pay attention to the evaluation of facilities and the close relationship between residents, while for accessible products, they pay more attention to improving the user experience and performance of products. For example, Liu et al. took Beijing, China, as the research object and used accessibility data and mobile phone data to propose a comprehensive framework for evaluating accessibility facilities, revealing the significant aggregation and heterogeneity of accessibility facilities in Beijing [25]. Zhang et al. discussed the construction methods and current situation of the accessible public activity facility system from the perspective of public service facilities, a tactile pavement system, and activity area, based on the spatial activity data of the elderly and the disabled [26]. Hou et al. took dust and accessible facilities in the living environment as the evaluation objects, collected data by means of health questionnaires, and analyzed them by using multi-layer logistic regression to explore the close relationship between the living environment and population depression [27]. Zhang et al. established a comprehensive evaluation framework based on the subway stations of public transport. They evaluated the accessible performance of the subway by using the analytic hierarchy process and the system availability scale, and verified the reliability of the framework [28].

As for accessible products, Chen et al. took wheelchairs as the research object of accessible facilities, and proposed a method of accessible path planning and a measurement standard of an accessible evaluation index of wheelchairs [29]. Vedu et al. developed a smart watch for the blind through deep learning technology, and verified the applicability of the watch [30]. Liu et al. developed the intelligent bionic hand [31], Sun et al. manufactured the intelligent bionic leg [32], Chatterjee et al. produced a hybrid control wheelchair [33], and Picallo et al. produced augmented reality glasses [34] equipped with wireless system integration and sensors with high flexibility, which were successfully applied in the nursing activities of intelligent physiotherapy. Xue et al. have created an auxiliary robot [35] combining magnetorheological elastomer, an electromagnetic control system, and bionic movement, which greatly helps the elderly improve their quality of life.

To sum up, scholars have explored the digital economy, accessible design, accessible facilities, and products from multiple dimensions, and have achieved rich research results. They have empirically investigated the economic effects of the digital economy and the positive impact of the digital economy on industrial development. However, previous studies only focused on a single object, such as the elderly, the disabled, or children, or accessible design, products, or facilities. They all ignored the synergy and linkage effect between the multi-dimensional factors behind the development of the industry, lacked an overall understanding of the accessible industry, and ignored the impact of the digital background on the development of the industry. From the perspective of academic theory, the role of the digital economy in promoting the accessible industry has not yet been elaborated. Accordingly, this paper analyzes the development status of the digital economy at the provincial level in China, and uses the three-stage DEA model to analyze the development efficiency of accessible industries enabled by the digital economy. At the same time, it compares the input–output efficiency of accessible industries with the development of the digital economy, and puts forward the mechanism of efficiency improvement and policy suggestions, to fill the gap in research on accessible industries and the digital economy, and to provide a reference for the further high-quality development of accessible industries.

3. Mechanism of Digital Economy Enabling Accessible Industry Efficiency Improvement

The main enabling bodies of the digital economy include the government, enterprises, and society, which form a closed-loop effect of policy guidance, enterprise promotion, and social participation under the synergy of the three parties [36]. The digital economy is mainly composed of digital technology and important production factors [37]. The accessible industry is mainly represented by accessible design, accessible facilities, and accessible products. Of course, it also includes the upstream of the industrial chain. With the rapid development of the digital economy and the catalysis of big data, artificial intelligence, and blockchain technology smart accessibility has increasingly become a necessary guarantee for promoting the supply-side reform of accessible industries [38]. Traditional accessible design focuses on the physical environment, such as architecture [39]. With the help of advanced information technology means such as virtual reality (VR) and augmented reality (AR), accessible design can be extended to the digital space, which can provide more intelligent services and products for the elderly and disabled groups. The development of the digital accessible industry can integrate resources and optimize the supply of factors, accurately guarantee elderly care and disability services, and then enable industrial transformation and efficiency improvement. Based on this, this paper expounds the mechanism of improving the efficiency of the digital economy-enabled accessible industry from four aspects: the enabling body, accessible design, and accessible facilities and products.

In the era of the digital economy, the government, as the top-level designer, can promote the digital construction of accessible infrastructure and the full coverage of digital services in the form of government procurement and subsidies by equating public policies and using financial funds. Enterprises can optimize accessible services by applying AI, big data, and other technological innovations to improve their production efficiency and service level through policy accuracy and market orientation. Society mainly aims at social benefits, through the digital platform, the construction of public welfare organizations, and the commercial operation of enterprises to improve the efficiency of accessible resource supply.

The application of digital technology in the field of accessible design can significantly optimize the design process [40], reduce the design cost, and improve the design efficiency. For example, through the data model predicting the operation path of different user groups, VR/AR simulates the use scenarios of visually impaired, hearing-impaired, or disabled people, and helps designers intuitively feel the obstacles to optimize the design process. At the same time, the accessible concept can be advanced to the planning and design stage through big data and artificial intelligence (AI), which can significantly reduce the design cost compared with the traditional accessible transformation, which is often carried out after the completion of the facilities. In addition, digital tools such as axe and wave have the functions of quickly scanning web pages to identify accessible defects at the code level and reduce manual inspection time, while digital prototype tools allow rapid testing of a variety of accessible solutions, accelerate design verification, and improve design efficiency.

Digital technology gives accessible facilities and products more labels [41], intelligence, personalization, and convenience. For example, intelligent products include intelligent assistive devices, smart homes, intelligent robots, etc., which can not only collect data from cameras and sensors, process data using edge computing, but also use an AI algorithm for data analysis, accurately predict the needs of the elderly and the disabled, simplify work procedures, and realize convenient innovation. In addition, according to the living habits and requirements of the elderly and the disabled, through the integration of big data, personalized and differentiated products and services can be provided. For example, the quality of life and user experience of the elderly and the disabled have been greatly improved by private customized intelligent aids, personalized meal aid, bath aid, medical aid, etc.

Through combining the impact mechanism of the digital economy on the development of the accessible industry, this paper lays a theoretical foundation for further research. Based on this, combined with the three-stage DEA model, a theoretical framework for improving the efficiency of accessible industries enabled by the digital economy is constructed, as shown in Figure 1.

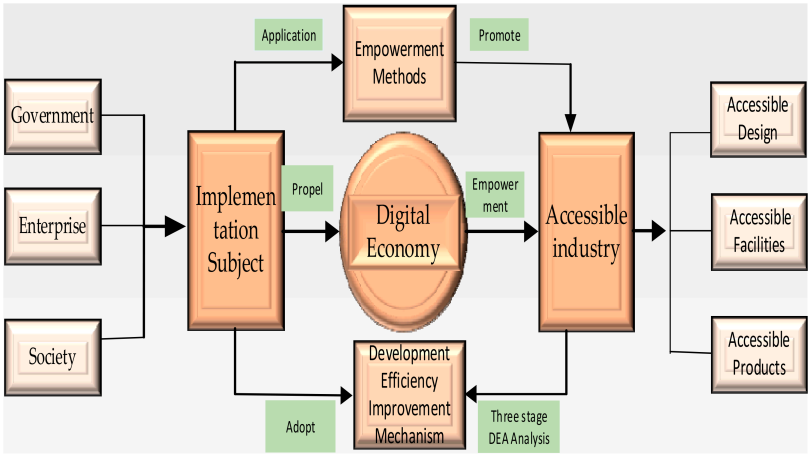


Figure 1. Theoretical framework of the digital economy empowering the development of accessible industries and efficiency improvement.

4. Model Design

4.1. Three-Stage DEA Model

The traditional data envelopment analysis (DEA) method is widely used in efficiency evaluation [39]. In the DEA model, the decision-making unit (DMU) is the evaluation object, representing the entity that converts specific inputs into specific outputs. In the evaluation of the development efficiency of barrier industries, DMU is an accessible industry.

The DEA method uses linear programming to evaluate relative effectiveness according to a number of input and output indicators. This method does not need to determine the production function and parameters, conforms to the multi-input and multi-output characteristics of accessible industries, can objectively evaluate industrial development, and has been widely used in economic and industrial efficiency evaluation to provide management information for competent departments [40]

Fried et al. [41] pointed out that although the traditional DEA model is used as a method to measure the relative effectiveness of each decision-making unit, it does not place the decision-making unit in the same environment, resulting in deviation in the assessed efficiency. To solve this problem, a three-stage DEA model is proposed. This model is an improved efficiency evaluation method. By introducing SFA regression as a measurement tool, it skillfully solves the inherent defect that the traditional DEA model cannot deal with the external environment and random interference. Therefore, this paper uses the three-stage DEA model to explore the development efficiency evaluation and mechanism of the accessible industry enabled by the digital economy. Therefore, we build the following model.

The first stage: the dual DEA-BCC model

In view of the characteristics of accessible industries and the constant limit of scale reward, the investment-oriented model is set as follows.

$$\begin{aligned} &min\theta - \varepsilon(\hat{e}^{T} S^{-} + e^{T} S^{+}) \\ s.t. &\begin{cases} \sum_{i=1}^{n} X_i \lambda_i + S^{-} = \theta X_0 \\ \sum_{i=1}^{n} Y_i \lambda_i - S^{+} = Y_0 \\ \lambda_i \geq 0, S^{-}, S^{+} \geq 0 \end{cases} \end{aligned} \tag{1}$$

In Equation (1) [42,43], i represents the number of decision-making bodies, and the number is 31. X and Y, respectively, represent the input and output vectors of the digital economy development of accessible industries, S^{-} and S^{+} represent the relaxation variables of input and output in the development of the digital economy of accessible industries, and ε represents the Archimedean infinitesimal.

The second stage: a similar SFA regression model

Based on the relevant research of Fried et al. (2002) [44], the environmental variables were standardized to build a similar SFA model, and the relevant data were regression analyzed, as follows:

$$S_{ni} = f(Z_i;\ \beta_n) + \nu_{ni} + \mu_{ni};\ i = 1, 2, \ldots, I; n = 1, 2, \ldots, N \tag{2}$$

In Equation (2) [45], S_{ni} represents the relaxation variable of digital economic development investment; Z_i represents industry, policy, and urbanization environmental variables and β_n represents the coefficient of environmental variables; and $\nu_{ni} + \mu_{ni}$ is the mixed error term, ν is random interference, and μ stands for inefficient management. Among them $\nu \sim N(0, \sigma^2)$ is the random error term, representing the impact of factors such as management on input relaxation variables; $\mu \sim N(0, \sigma^2)$ denotes that it is believed that the distribution follows the normal distribution of truncation at zero.

According to the results of similar SFA regression, the input variables are adjusted to eliminate the interference of environment and random factors on efficiency measurement, so as to ensure that all decision-makers are in the same external environment. The specific equation is as follows:

$$X_{ni}^{A} = X_{ni} + \left[\max(f(Z_i;\hat{\beta}_n)) - f(Z_i;\hat{\beta}_n)\right] + [\max(v_{ni}) - v_{ni}] \quad i = 1,2,\ldots,I;\ n = 1,2,\ldots,N \tag{3}$$

In Equation (3) [46,47], X_{ni}^{A} and X_{ni} represent the input value after adjustment and before adjustment, respectively; $\left[\max(f(Z_i;\hat{\beta}_n)) - f(Z_i;\hat{\beta}_n)\right]$ is to adjust the industry, policy, and urbanization environment variables; and $[\max(v_{ni}) - v_{ni}]$ means to adjust the decision-making body to the same level.

The third stage: the adjusted DEA model

The original input value is replaced by the adjusted input value, and the output data is not processed. The DEA-BCC model is used to measure again, and the real efficiency value excluding environmental factors and random interference factors is obtained.

4.2. Indicator Setting

4.2.1. Output Indicators

The scale and innovation of accessible industry development are two output dimensions. The change in accessible industry output value in the scale dimension can better reflect the growth of the accessible industry. Therefore, in the three-stage DEA, the accessible industry output value is taken as the output variable. At present, China has not yet established a perfect statistical system for accessible industries, and there is no statistical channel for accessible industries, let alone sufficient data on accessible industries. Accessible industries have great difficulties in statistics. Ghoreishi proposed that the most basic method of scientific research on aging is age structure analysis [48], which is an important way to solve many practical problems. The elderly and the disabled are the main service objects of the accessible industry. The proportion of the elderly and the disabled can reflect the potential demand for accessible services in a region or country. Based on the age analysis method and referring to Guo, X's method of estimating the output value of the elderly care industry [49], this paper estimates the output value of the accessible industry by multiplying the proportion of China's GDP and the sum of the elderly population aged 60 and above, plus the disabled population. In the innovation dimension, it is measured by the number of patent authorizations.

4.2.2. Input Indicators

Based on the analysis of the mechanism of enabling accessible industries in the digital economy, the input index is divided into two dimensions: fixed assets and R&D investment. The fixed assets dimension includes information and software, finance, scientific research, and other inputs, respectively; the R&D investment dimension includes R&D personnel investment and expenditure.

4.2.3. Environmental Indicators

The environment is mainly divided into four dimensions: economy, culture, politics, and society. Among them, the economic environment dimension refers to the economic development level of the region, with the per capita GDP of the region as the measurement index; the dimension of cultural environment refers to the education level of residents in the region, and the average number of years of education in the region is taken as the

measurement index; the dimension of political environment refers to the support of the local government, which is measured by the proportion of local fiscal expenditure in GDP; and the social environment dimension refers to the urbanization level of the region, which is measured by the proportion of the local urban population in the total local population.

4.3. Data Sources

This paper selects 31 provinces and cities in China (Hong Kong, Macao: data missing, not in the scope of this study) as the decision-making body, and adheres to the basic principle of "sufficient samples and easy access" to explore the promotion mechanism, evaluation, and influencing factors of the development efficiency of accessible industries enabled by the digital economy. The input index data are from the *Statistical Yearbook of China* and the *Statistical Yearbook of Science and Technology of China*, the output index data are from the *Statistical Yearbook of Provinces and Cities in China* and the *Statistical Yearbook of Disabled People in China*, and the environmental index data are from the *Statistical Yearbook of China*. All research data are based on 2024. See Table 1 for details.

Table 1. Indicator system.

Primary Indicator		Secondary Indicator
Input Indicators	Investment in fixed assets	Information transmission, software, and information technology service industry *A1* (in billions of yuan)
		Financial industry *A2* (in billions of yuan)
		Scientific research and technology service industry *A3* (in billions of yuan)
		Education investment *A4* (in billions of yuan)
	R&D investment	R&D personnel *A5* (10,000 people)
		R&D expenditure *A6* (in billions of yuan)
Output Indicators (Benefit)	Scale	Total output value of the accessible industry *TP1* (in billions of yuan)
	Innovate	Number of patents granted *TP2* (units) [50]
Environmental Indicators	Economic	Per capita GDP *B1* (10,000 yuan)
	Culture	Education level of residents *B2* (year)
	Politics	Government support *B3* (%)
	Society	Urbanization level *B4* (%)

4.4. Correlation Analysis

Before using the DEA model to analyze the development efficiency of the accessible industry, the Pearson method should be used to analyze the correlation of the index system to verify the "unidirectionality" of the six input indicators and two output indicators [51]. As shown in Table 2, the input and output indicators of accessible industries are positively correlated, indicating that the selected input and output indicators meet the relevant requirements of "unidirectionality".

Table 2. Pearson correlation analysis.

Variable	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*
TP1	0.603 ***	0.573 ***	0.708 ***	0.814 ***	0.659 ***	0.657 ***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
TP2	0.389 **	0.766 ***	0.442 **	0.424 **	0.981 ***	0.975 ***
	(0.031)	(0.000)	(0.013)	(0.018)	(0.000)	(0.000)

Note: *** and ** respectively represent a significant correlation between 1% and 5% levels (bilateral); the *p* value in brackets represents the correlation analysis.

5. Empirical Results and Analysis

5.1. The Development Efficiency of the Accessible Industry Based on the DEA BC2 Model

Using DEAP2.1 software, we measured the development efficiency of the accessible industry in 31 provinces (cities). The results are presented in Table 3.

Table 3. Development efficiency of accessible industries in China.

Region	Comprehensive Efficiency (TE)	Pure Technical Efficiency (PTE)	Scale Efficiency (SE)	Returns to Scale (RS)	Region	Comprehensive Efficiency (TE)	Pure Technical Efficiency (PTE)	Scale Efficiency (SE)	Returns to Scale (RS)
Beijing	1.000	1.000	1.000	-	Hubei	1.000	1.000	1.000	-
Tianjin	0.909	0.917	0.991	irs	Hunan	0.385	0.742	0.518	drs
Hebei	0.650	1.000	0.650	drs	Guangdong	1.000	1.000	1.000	-
Shanxi	1.000	1.000	1.000	-	Guangxi	0.875	1.000	0.875	drs
Inner Mongolia	0.860	0.881	0.976	irs	Hainan	1.000	1.000	1.000	-
Liaoning	1.000	1.000	1.000	-	Chongqing	0.798	0.799	0.999	irs
Jilin	1.000	1.000	1.000	-	Sichuan	0.713	1.000	0.713	drs
Heilongjiang	1.000	1.000	1.000	-	Guizhou	0.934	1.000	0.934	drs
Shanghai	1.000	1.000	1.000	-	Yunnan	0.962	1.000	0.962	drs
Jiangsu	0.977	1.000	0.977	drs	Xizang	1.000	1.000	1.000	-
Zhejiang	1.000	1.000	1.000	-	Shaanxi	0.903	1.000	0.903	drs
Anhui	0.710	0.937	0.758	drs	Gansu	1.000	1.000	1.000	-
Fujian	0.643	0.679	0.947	drs	Qinghai	0.851	1.000	0.851	irs
Jiangxi	0.545	0.684	0.797	drs	Ningxia	1.000	1.000	1.000	-
Shandong	0.669	1.000	0.669	drs	Xinjiang	0.875	0.882	0.992	drs
Henan	0.581	1.000	0.581	drs	Mean	0.866	0.952	0.906	

Note: "drs" indicates decreasing, "-" indicates no change, and "irs" indicates increasing.

Table 3 reveals that the average development efficiency of the accessible industry empowered by the digital economy is 0.866, with a pure technical efficiency average of 0.952 and a scale efficiency average of 0.906. Among them, the province (city) with the lowest development efficiency is Hunan Province, with a value of only 0.385, while the 13 provinces (cities) with the highest development efficiency, including Beijing, Shanxi, Liaoning, and Jilin, have a value as high as 1.000 and are at the frontier of technical efficiency. This indicates that the overall development level of these provinces (cities) is relatively high in terms of the coordinated development of digital economy investment and accessible industry output efficiency. The digital economy helps to improve the development efficiency of the accessible industry. However, the development efficiency values of provinces such as Jiangxi and Henan are only around 0.5, indicating significant regional differences in the impact of digital economy investment on the development of the accessible industry. It also suggests that these provinces (cities) with lower development efficiency values have considerable room for improvement and are experiencing resource inefficiency, requiring further optimization through adjustments to relevant resource allocation. Considering that the development efficiency of the accessible industry in the one-stage DEA model analysis is subject to dual interference from environmental and random factors, there may be certain deviations in the development efficiency values of the accessible industry empowered by the digital economy. Therefore, further analysis and verification are necessary.

5.2. The Second Stage: Similar SFA Model Regression

Using the Frontier 4.1. software, we further conducted regression analysis on the relevant data from the first stage using a similar SFA model. The relevant computational equations were referenced from the related research by Melgarejo, Z [52]. The specific analysis results are presented in Table 4.

Table 4. The second stage: SFA model regression results.

	Relaxation Variable					
Variable	***A1***	***A2***	***A3***	***A4***	***A5***	***A6***
Constant term	132.530 ***	25.800 ***	19.530 ***	284.040 ***	4.980 ***	214.160 ***
	(268.340)	(25.770)	(18.810)	(153.960)	(5.020)	(214.590)
B1	−0.130	−0.020	−0.040 ***	−0.050 ***	0.001	−0.110 ***
	(−1.040)	(−0.900)	(−35.290)	(−5.730)	(−0.540)	(−3.180)
B2	−43.280 ***	−7.130 ***	57.630 ***	−49.410 ***	−0.820 ***	−44.320 ***
	(−5.370)	(−28.530)	(470.660)	(−8.860)	(−5.010)	(−57.490)
B3	−167.320 ***	−30.540 ***	−661.880 ***	−372.290 ***	−9.220 ***	−294.590 ***
	(−610.870)	(−27.990)	(−660.220)	(−344.880)	(−9.530)	(−294.630)
B4	443.440 ***	66.880 ***	−755.260 ***	297.990 ***	6.420 ***	368.950 ***
	(551.190)	(62.310)	(−742.130)	(200.960)	(6.450)	(369.300)
σ^2	46,759.490 ***	313.060 ***	176,796.440 ***	51,252.120 ***	18.160 ***	15,167.230 ***
	(46,764.682)	(312.020)	(176,796.430)	(51,252.100)	(22.540)	(15,167.230)
γ	1.000 ***	1.000 ***	1.000 ***	1.000 ***	1.000 ***	1.000 ***
	(49,225.490)	(46,506.510)	(10,313,784.000)	(42,073.400)	(103,405.010)	(839,384.170)
loglikelihood	−183.460	−107.890	−203.180	−187.610	−63.070	−170.300
LR-test	25.600	22.050	27.900	20.160	22.920	17.030

Note: "***" represent 1% significant levels, and the brackets represent the T value of the SFA model regression analysis.

Since the environmental variable is a regression of the relaxation variable, when the regression coefficient is negative, it means that increasing the value of the environmental variable is conducive to reducing the amount of input relaxation. When the regression coefficient is positive, it means that increasing environmental variables will increase input slack. The impact of the four environmental variables on each input relaxation variable is analyzed as follows:

(1) Per capita GDP (*B1*): The per capita GDP level has a negative correlation with the investment in scientific research and technical services (*A3*), education investment (*A4*), and R&D expenditure (*A6*), and has passed the 1% significance level test. It shows that the higher the per capita GDP, the higher the supply efficiency of scientific research and technical services (*A3*), education investment (*A4*), and R&D expenditure (*A6*). And the per capita GDP and information transmission, software and information technology services (*A1*) and financial industry (*A2*) also showed a negative correlation. R&D personnel (*A5*) showed a positive correlation, but did not pass the significance test, indicating that the increase in per capita GDP has no direct relationship with information transmission software and information technology services (*A1*), financial industry (*A2*) investment and R&D personnel (*A5*) investment. This may be because the growth of per capita GDP is more driven by the real economy, and the proportion of information transmission, software, and information technology services (*A1*), financial industry (*A2*), and research funds in the total economy is smaller.

(2) The number of years of education per capita (*B2*): This variable is only positive for the regression coefficient of scientific research and technical services (*A3*) investment, and has passed the significance test, indicating that the increase in per capita education years will increase the relaxation of investment, which is not conducive to the improvement of accessible industrial development efficiency. The relaxation variable regression coefficient of this variable for information transmission software and information technology service industry (*A1*), financial industry (*A2*) investment, investment in education (*A4*), R&D personnel (*A5*) investment, and R&D expenditure (*A6*) is negative, and passed the significance level test, which shows that the higher the education level, the higher the information transmission software and information technology service industry (*A1*), financial industry (*A2*) investment, education investment (*A4*), R&D personnel (*A5*) investment, and R&D ex-

penditure (*A6*) investment efficiency. This shows that the improvement of cultural level can cultivate more elite talents, and increase perfect knowledge reserves and professional skills, which is conducive to improving the level of local financial and technological research and development, so as to achieve the improvement of efficiency.

(3) Government support (*B3*): This variable is negatively correlated with six types of input, and is significant at the level of 1%, indicating that the government's increased support is conducive to the improvement of supply efficiency of information transmission software and information technology service industry (*A1*) investment, financial industry (*A2*) investment, scientific research and technology service industry (*A3*) investment, education investment (*A4*), R&D personnel *(A5*) investment, and R&D expenditure (*A6*).

(4) The urbanization level (*B4*): The level of urbanization is negatively related to the investment in scientific research and technical services (*A3*), and has passed the 1% significance level test. It shows that the higher the level of urbanization, the faster the supply efficiency of scientific research and technical services (*A3*) improves, and the improvement of the urbanization level will weaken the redundancy of input variables. The level of urbanization is positively correlated with the input of information transmission software and information technology services (*A1*), financial industry (*A2*), education (*A4*), R&D researchers (*A5*), and R&D expenditure (*A6*), and has passed the 1% significance level test. It shows that the improvement of the urbanization level will increase the relaxation of information transmission software and information technology service industry (*A1*), financial industry (*A2*) investment, education investment (*A4*), R&D personnel (*A5*) investment, and R&D expenditure (*A6*), which is not conducive to the improvement of supply efficiency.

5.3. The DEA Estimation Results After Adjusting the Input in the Third Stage

Using DEAP2.1 software to measure the data again, we replace the original input value with the input value after a similar SFA model analysis. The output data is not processed, and the accessible industrial development efficiency is analyzed again. The results are shown in Table 5.

Table 5. The development efficiency of accessible industries in various provinces (cities) after adjustment.

Region	Comprehensive Efficiency (TE)	Pure Technical Efficiency (PTE)	Scale Efficiency (SE)	Returns to Scale (RS)	Region	Comprehensive Efficiency (TE)	Pure Technical Efficiency (PTE)	Scale Efficiency (SE)	Returns to Scale (RS)
Beijing	1.000	1.000	1.000	-	Hubei	1.000	1.000	1.000	-
Tianjin	0.835	1.000	0.835	irs	Hunan	0.551	0.742	0.742	drs
Hebei	0.829	0.923	0.829	drs	Guangdong	1.000	1.000	1.000	-
Shanxi	1.000	1.000	1.000	-	Guangxi	1.000	1.000	1.000	-
Inner Mongolia	0.847	1.000	0.847	irs	Hainan	0.612	0.992	0.664	irs
Liaoning	1.000	1.000	1.000	-	Chongqing	1.000	1.000	1.000	-
Jilin	1.000	1.000	1.000	-	Sichuan	0.974	1.000	0.974	drs
Heilongjiang	1.000	1.000	1.000	-	Guizhou	1.000	1.000	1.000	-
Shanghai	1.000	1.000	1.000	-	Yunnan	1.000	1.000	1.000	-
Jiangsu	1.000	1.000	1.000	-	Xizang	0.240	1.000	0.240	irs
Zhejiang	1.000	1.000	1.000	-	Shaanxi	0.998	1.000	0.998	irs
Anhui	0.934	0.959	0.974	drs	Gansu	0.864	1.000	0.864	irs
Fujian	0.740	0.752	0.984	irs	Qinghai	0.212	0.964	0.220	irs
Jiangxi	0.750	0.774	0.968	irs	Ningxia	0.485	1.000	0.485	irs
Shandong	0.835	1.000	0.835	drs	Xinjiang	0.607	0.751	0.808	irs
Henan	0.735	1.000	0.735	drs	Mean	0.840	0.963	0.871	

Note: "drs" indicates decreasing, "-" indicates no change, and "irs" indicates increasing.

To deeply analyze the differences in the level of development efficiency among provinces and cities in China, and to clarify the impact of environmental factors, the development efficiency values, technical efficiency values, and scale efficiency values of

the above provinces before and after the adjustment are respectively plotted as shown in Figures 2–4. It can be clearly seen from the three figures that the development efficiency value, technical efficiency value, and scale efficiency value of different provinces have changed before and after the adjustment.

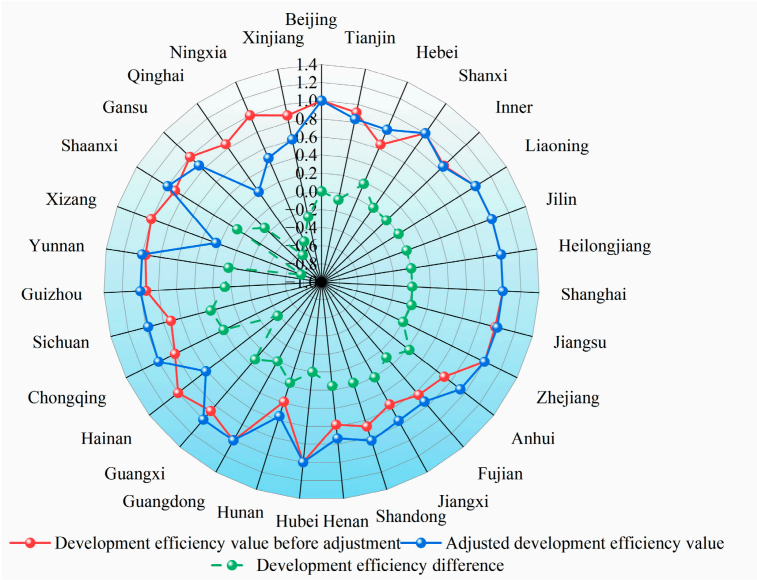


Figure 2. Changes in development efficiency values of provinces and cities before and after adjustment.

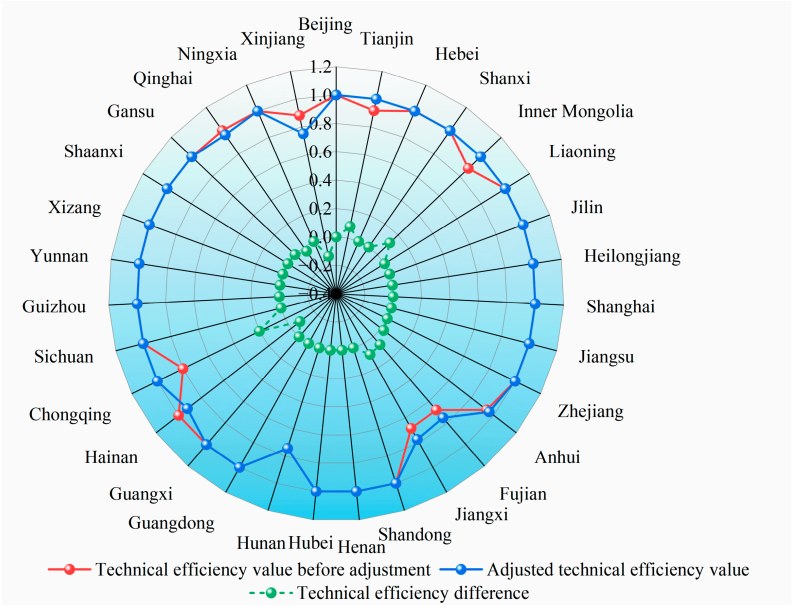


Figure 3. Changes in technical efficiency values of provinces and cities before and after adjustment.

It can be seen from Figure 2 that, on the whole, the development efficiency value of the accessible industry after adjustment is significantly lower than that of the first stage. That is, after eliminating the influence of environmental factors, the average development efficiency value of the accessible industry in each province (city) has changed from 0.866 to 0.840. From Figure 4, it can be found that the scale efficiency value has changed from 0.906 to 0.871, respectively, and the pure technical efficiency in Figure 3 has slightly rebounded from 0.952 to 0.963. This shows that the development efficiency of the accessible industry in each province (city) is greatly affected by economic, cultural, political, social, and other environmental factors and random interference factors. From the perspective of the

situation of each province after the adjustment, the development efficiency is at the forefront of technology in 14 provinces, such as Beijing, Shanxi, Liaoning, and Jilin, and 12 provinces, such as Tianjin, Hebei, and Fujian, are lower than the system average. The last three places have changed from Hunan (0.385), Jiangxi (0.545), and Henan (0.581) before the adjustment to Qinghai (0.212), Tibet (0.240), and Ningxia (0.485), which are all caused by the low scale efficiency. There are 24 provinces with a pure technical efficiency of 1, four of which are lower than the system average. The last three places have changed from Fujian (0.679), Jiangxi (0.684), and Hunan (0.742) before adjustment to Hunan (0.742), Xinjiang (0.751), and Fujian (0.752). The main reasons are the use of digital technology, the introduction of advanced machinery and equipment, the scientific guidance of accessible facilities, the active participation of product operators and service subjects, and the continuous optimization of the allocation of production resources. There are 14 provinces with a scale efficiency of 1, and 12 provinces are lower than the system average. The last three places have changed from Hunan (0.518), Henan (0.581), and Hebei (0.650) before adjustment to Qinghai (0.220), Tibet (0.240), and Ningxia (0.485). The main reason is that the number of elderly people and disabled people in these provinces is relatively small and relatively scattered, without the scale effect.

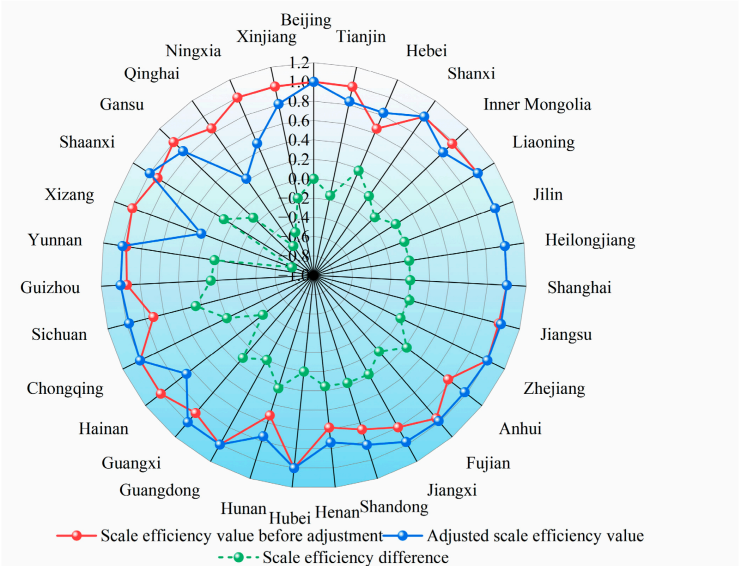


Figure 4. Changes in the scale efficiency values of provinces and cities before and after the adjustment.

It is worth noting that after the adjustment, the development efficiency of Tibet, Qinghai, Ningxia and other provinces (cities) has changed from DEA effective to invalid, and the development efficiency of Tibet has declined sharply by 76%, indicating that the lack of government support and other environmental factors in these provinces (cities) will lead to the redundancy of digital economy investment and indirectly reduce the development efficiency of accessible industries. After the adjustment, the development efficiency of accessible industries in some provinces (cities), such as Sichuan, Chongqing, and Anhui, has increased slightly, which also shows that environmental factors and random factors have a certain inhibitory effect on the improvement of the development efficiency of accessible industries in these provinces (cities).

In order to further analyze the development efficiency of accessible industries in various provinces (cities), China's provinces (cities) are divided into four types, as shown in Table 6.

Table 6. Distribution of accessible industries in 31 provinces (cities) of China.

Level	Division Standard	Province (Cities)
High-quality and efficient	Development efficiency = 1.000	Beijing, Shanxi, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Hubei, Guangdong, Guangxi, Chongqing, Guizhou, Yunnan
Relatively efficient type	0.900 ≤ development efficiency < 1.000	Anhui, Sichuan
Development potential type	0.600 ≤ development efficiency ≤ 0.900	Tianjin, Hebei, Inner Mongolia, Fujian, Jiangxi, Shandong, Henan, Hainan, Gansu, Xinjiang
Inefficient improvement type	0.000 ≤ development efficiency < 0.600	Hunan, Xizang, Qinghai, Ningxia

It can be found from Table 6 that, first of all, most provinces and cities in China are high-quality and relatively efficient, and that these are geographically distributed in Beijing, Shanghai, and Northeast China. These regions have more top 100 colleges and universities, rich educational resources, leading scientific and technological research and development in China, and accessible facilities that are relatively perfect compared with other regions, proving that the investment in digital economy development can have a positive impact on the development efficiency of accessible industries. Secondly, four provinces and cities are inefficient and need improvement, including Ningxia, Qinghai, Tibet, and Hunan. It should be noted that as Hunan Province's total economic output is 5001.29 billion yuan, ranking ninth in the country, and its per capita GDP reaches 67,100 yuan, ranking 15th in China, its economic development level is relatively high. The financial industry has invested 1.738 billion yuan, ranking 12th in China, and the province has three well-known universities: Hunan University, National University of Defense Technology, and Central South University. It has rich educational and scientific research resources and large investment in the digital economy, but the development of the accessible industry is relatively slow and inefficient, which may be related to factors such as the market environment for the development of the accessible industry and the scale of the industrial chain, resulting in more input and less output, and high input and low efficiency.

6. Discussion

6.1. Mechanism of Efficiency Improvement Driven by Multiple Factors

It can be seen from Figure 2 that the development efficiency of Tibet, Gansu, Qinghai, and another eight provinces declined compared with that of the first stage, which shows that the development efficiency of accessible industries enabled by the digital economy is positively affected by environmental factors such as politics, economy, culture, society, and random interference factors. Therefore, the government, enterprises, society, and other implementers should actively create a good development environment. These provincial and municipal governments should enact regulations or laws for the construction of an accessible environment to adapt to the region, and force the realization of accessibility in multiple fields, so as to build a security framework covering the whole province. At the same time, we should enact a series of policies to promote the development of accessible industries, increase public financial expenditure through tax relief, and strengthen government procurement subsidies to promote the construction of accessible public service facilities. In addition, it is also necessary to establish a cooperation mechanism with developed regions to improve the scientific research level of education and accessible facilities and product research and development through the cooperation of universities and scientific research institutions in each province; it is further necessary to, through investment promotion, strengthen cooperation among enterprises, improve the level of economic development in the province, continue to promote the process of urbanization,

and create a good infrastructure environment. Enterprises should take the market demand as guidance to realize technological innovation by accelerating the digital transformation and promoting the application of digital technology. At the same time, new technologies such as artificial intelligence and the Internet of Things are deeply integrated with accessible facilities and product R&D, and R&D efforts are increased to promote digital solutions in the accessible field, so as to improve the efficiency of resource allocation. At the social level, the development of an accessible industry is mainly promoted by the combination of public welfare and business. The awareness and inclusiveness of the accessible industry are improved through the publicity and education of public welfare organizations and foundations. Through the business cooperation of enterprises, enterprises are guided to integrate accessibility into the social responsibility strategy, promote enterprises to improve the level of accessible design, develop accessible products, and improve service quality.

Compared with the development efficiency of the first stage, the development efficiency of Sichuan, Chongqing, Jiangxi, and 14 provinces and cities has increased, which shows that the development efficiency of accessible industries enabled by the digital economy is negatively affected by environmental factors and random interference factors. Therefore, the interference of environmental factors in the market should be reduced. These provincial and municipal governments may have blind expansion of public financial expenditure and loss-making government PPP (cooperation between government and social capital) projects. Although the level of economic development is high, they are more focused on the electronic information industry and equipment manufacturing industries. Taking Sichuan Province as an example, the largest industry is the first material industry, with a scale of more than 1 trillion yuan, followed by the equipment manufacturing industry, with an output value of 854.88 billion yuan. Other industries also rank among the top in the country, while the accessible industry ranks only 21st in the country. At the same time, Sichuan University, the University of Electronic Science and Technology, and other famous universities in the province are rich in educational resources, which may be due to the lack of integration and transformation of production and education, and the failure to promote the transformation of achievements to promote the rapid development of enterprises. Based on this, these provincial and municipal governments should strengthen cooperation with enterprises, create incentive policies more conducive to the release of market potential through demand research and resource integration, and focus on special financial expenditures for accessible industries. At the same time, the government should purchase accessible facilities, appliances, and other products, and guide or force the purchase and use of accessible products in the construction of public facilities through policies. Enterprises should efficiently integrate production and education with local enterprises, strengthen scientific and technological research and development, promote the transformation of relevant achievements, and set up functional departments, such as accessible business in the internal organizational structure of the enterprise to enhance the awareness of accessible products and expand the market share of the enterprise with the help of the brand effect of the enterprise. At the social level, we should establish specific associations or social work organizations, streamline the allocation of social resources, and pay more attention to the construction of regional accessible centers.

6.2. Mechanism of Regional Synergy Promotion

Compared with the development efficiency of the first stage, Beijing, Shanxi, Heilongjiang, and nine provinces remain unchanged and maintain the highest efficiency value. Among them, Beijing, Shanghai and other developed regions benefit from the high economic level and the speed of policy implementation; the demand for accessible industries is highly concentrated, the market competition is stimulated and the development is relatively

mature, while Heilongjiang and Jilin are located in the border areas, and the economic development is relatively backward, but they benefit from the rich educational resources, with many universities such as Harbin Institute of Technology and Jilin University, which effectively promote the application of digital technology in accessible industries and improve the efficiency of resource allocation [53]. In view of this, we can build the mechanism of regional collaborative promotion based on the similarities of geographical distribution and resources. Hebei, Fujian, and other provinces and cities in the eastern region can, through system design, resource integration, and policy linkage with Beijing, Guangdong and other provinces and cities, respectively, promote the complementary advantages of accessible industries in the region, promote the linkage development of digital technology, help break technical barriers, promote the efficient allocation of resources and improve efficiency [54]. Similarly, Henan and other inefficient provinces and cities in the central region can also cooperate with Shanxi Province in the field of accessible design and accessible public implementation and products to drive the industrial development of the region. Due to the complex and diverse terrain and rich resources in the western region, the capital and technology of provinces and cities in the eastern region can be used to develop accessible industry centers, and the mature experience of accessible industry development in provinces and cities in the central region can be reproduced and used to build a regional synergy mechanism suitable for the region. In addition, it can be seen from Table 6 that economically developed regions will also have low development efficiency. Therefore, it is also necessary to create a good industrial development environment, expand the scale of the industrial chain with regional collaborative provinces and cities, and improve development efficiency through intelligent and more efficient ways.

7. Conclusions

In the first stage, without considering external factors and random error interference, the average development efficiency of 31 provinces and cities in China is high, which reflects that the digital economy is conducive to the development of accessible industries, while the development efficiency value of Jiangxi and Henan provinces is only about 0.5, which also exposes the significant difference in the process of regional development, and has great room for improvement. The two-stage SFA regression test shows that government support has a negative correlation with each input slack variable, indicating that increasing government support is conducive to improving the efficiency of digital economy investment. The level of urbanization has a positive correlation with input slack variables except for scientific research and technical services, indicating that the improvement of the level of urbanization will increase the amount of input slack, which is not conducive to the improvement of supply efficiency. The per capita and per capita years of education also have different correlations with each input relaxation variable. After eliminating the environmental factors in the three stages, the average development efficiency of 31 provinces and cities in China has decreased significantly, and the effective number of DEA has decreased, mainly due to the impact of environmental factors such as the lack of government support in these provinces (cities), which will lead to the redundancy of digital economy investment and indirectly reduce the development efficiency of accessible industries. Further analysis can conclude that the development efficiency can be divided into high-quality and efficient type, relatively efficient type, development potential type, and inefficient improvement type. Among the low efficiency improvement types, the economically developed Hunan Province is also included, which may be related to the market environment, industrial chain scale, and other factors, resulting in more input and less output, and showing the phenomenon of high input and low efficiency. Based on

this, this paper puts forward the mechanism of multiple driving and regional collaborative promotions and relevant suggestions.

8. Suggestions

8.1. Improve the Standard System Construction of Accessible Industries

The improvement of the development efficiency of the enabling accessible industry of the digital economy is inseparable from the construction of the industrial standard system, which plays a legal role in optimizing the allocation of resources. The standard system should include design standards, implementation rules, supervision, rewards and punishments, and other systems. The design standard should integrate digital technology, artificial intelligence, and intelligent application of the Internet of Things, and do a good job in high-level design; the implementation rules should clarify the legal responsibilities and obligations of the government, enterprises, and society. The government should mobilize the enthusiasm of enterprises to participate in serving society by means of tax leverage and reputation binding, while society can supervise the government and enterprises by means of complaints. The state or local government should commend and reward enterprises, units, or individuals that have made contributions to the development of accessible industries. Those who violate the standards for the construction of accessible facilities should be handled by the relevant departments according to the law. In particular, inefficient and improved provinces such as Qinghai should not only learn from high-quality and efficient provinces, but also constantly improve the standardization system of barrier industries in the province, in combination with the local economic reality.

8.2. Promote the Digitalization Process of Accessible Industries

At this stage, China's accessible industry takes accessible facilities and products as an example. The production capacity of traditional facilities and appliances, such as accessible elevators, walkers, and braille devices, leads the world, but the added value is low, and the homogenization is serious. In contrast, emerging digital devices, such as intelligent bracelets and intelligent robots with rich types and complete functions, are growing rapidly and are more competitive. The government should promote the digital transformation of industries in provinces and cities, optimize the allocation of resources, give full play to the advantages of customization combined with digital technology, and accelerate the integration with the frontier information fields in the fields of artificial intelligence and augmented reality AR, to improve the quality and innovation efficiency of accessible facilities and services. In particular, the development potential type provinces and cities, through the promotion of digital technology, can improve development efficiency and enter the relatively efficient type, and are expected to speed up their entry into the high-quality and efficient type. Enterprises should upgrade their facilities and products through digital transformation, policy accuracy, and user participation, actively build a digital platform, realize user matching needs, data sharing optimization, and resource integration, broaden the revenue channels of accessible industries, and promote the diversified and high-quality development of industries.

9. Limitations and Further Research

Although this paper uses the three-stage DEA model to evaluate the efficiency of the accessible industry under the empowerment of the digital economy and explore its mechanism, it is the frontier direction of current research. However, this research paradigm still has significant limitations in theory adaptation, data acquisition, and model application, which may ignore the localization practice and ethical concerns. Further research should achieve the integration of methodology. On the basis of efficiency evaluation, combined

with SEM, QCA, game theory, and other methods to reveal the mechanism, use digital technology to carry out collaborative embedded analysis with local practice and ethics, and adhere to the value orientation to ensure that efficiency improvement serves the fundamental goal of inclusive development.

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