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A New Framework, Measurement, and Determinants of the Digital Divide in China

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Abstract: The digital divide (DD) reflects the inequality of the digital economy, while existing research lacks a comprehensive framework for investigating the measurement of DD and its determinants. This study constructs a new framework with a five-dimensional comprehensive index system. City-level data are used to measure China's DD index from 2010 to 2020 at the national, regional, and provincial levels. Furthermore, this study investigates the decomposition of DD at both regional and provincial levels and the determinants of DD from the perspectives of physical, human, and social capital. The key results are: (1) China's DD has generally exhibited a fluctuating downward trend. While it remains high in the eastern and western regions, it has shown a decline year by year. However, the DD within most provinces is on the rise. (2) The intra-regional and inter-provincial are the primary drivers of changes in national DD, with both intra-regional and intra-provincial contribution rates on the rise. (3) Economic growth, infrastructure, foreign trade, education, and online interaction significantly impact DD, and these determinants may change at different periods. This study intends to provide empirical support for bridging the DD, fostering the balanced development of the digital economy, and reducing social inequality.

Keywords: digital divide; digital economy; measurement; decomposition; determinant

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1. Introduction

Digital technology, which has greatly reduced production costs, facilitated industrial innovation, and improved productivity, is significantly driving changes in economic development and social structure [1]. The digital economy, an economy driven by digital technology, has also achieved rapid development in recent years [2]. Using the Internet as an example, according to International Telecommunications Union (ITU) statistics, global Internet users have steadily increased from 1 billion in 2005 to 5.3 billion in 2022. Moreover, the proportion of Internet users has steadily increased from 16% in 2005 to 66% in 2022 (Figure 1), which has greatly aided the growth of the global economy and improved citizen welfare.

As the world's second-largest economy, China's digital technology development is also rising significantly, particularly with the introduction of policies including "Broadband China" and "Digital China". However, China has a massive land area and a large population, and spatial disparities exist in the distribution of digital resources, including gaps in the digital abilities of different groups [3–5]. This case is conducive to neither coordinated development and inclusive growth nor industrial transformation and upgrading driven by digital technology. For instance, in China, the urban Internet penetration rate is as high as 85.1%, whereas the rural Internet penetration rate is only 60.5%, a difference of 24.6 percentage points, according to the 52nd Statistical Report on Internet Development in

China published by the China Internet Network Information Center (CNNIC). The inability of groups with low digital abilities to properly utilize digital technology to generate advantages would considerably reduce the inclusive effects of the digital economy and may even worsen the gap between income and living standards. Bridging the digital divide (DD), which represents the disparity in digital technology development, is thus crucial to promoting economic growth and reducing social inequality.

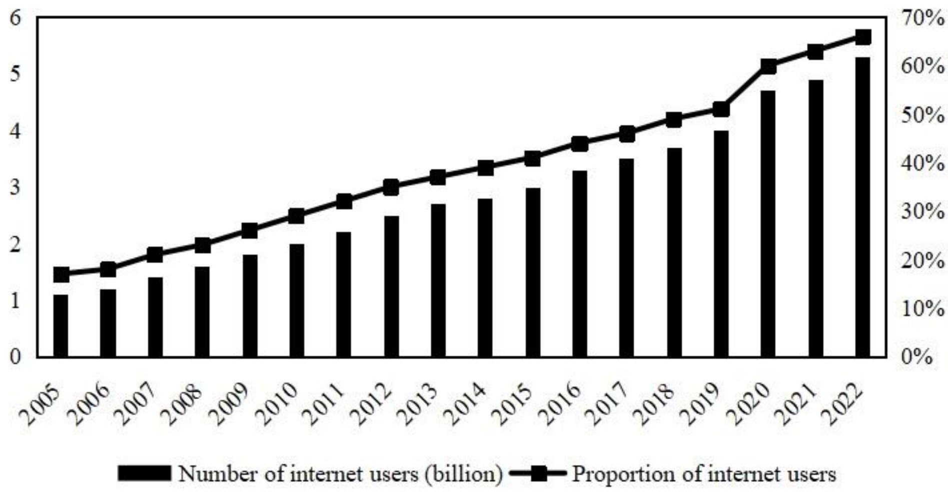

Figure 1. Global usage of the Internet.

The DD has gradually attracted global attention from international organizations, government departments, and academia since the end of the 20th century. Moreover, its connotation has been constantly enriched with the rapid development of digital technology. The current DD refers to the inequalities in access to, use, and benefits from information and communication technology (ICT) [6–8]. However, research on the measurement and determinants of the DD is limited, making it difficult to implement targeted policies to bridge the DD and eliminate inequities in society's use of digital technology. The few relevant studies can be divided into two groups. The first group comprises those studies that used multiple statistical methods to calculate the comprehensive index of digital economy or ICT among countries, identified the degree of DD through the relative size of the index, and examined the DD's influencing factors [9–12]. The other group comprises studies that conducted statistics on residents' digital skills through questionnaire surveys. The degree of DD is represented by individual differences in digital skills, and the determining factors are examined at the individual level [13–15].

Overall, although narrowing the DD is conducive to inclusive development, there is currently a lack of a unified measurement framework, good basic data, and accurate measurement methods. In addition, there is little research on the factors affecting DD. Specifically, the literature has the following limitations. First, owing to the rapid expansion of digital technology, the concept of DD has not been uniformly defined, which makes it difficult to measure the digital divide in a systematic framework. For example, some studies define DD as unequal use of Internet technology, which may ignore new digital technologies such as artificial intelligence [16,17]. Other studies define the digital divide from the perspective of digital life, which may ignore corporate behaviors such as digital manufacturing [18]. Second, relevant government survey data for quantifying DD are limited owing to data availability. The macro-level measurement of DD is limited to the national scale and lacks regional and detailed measures. Moreover, the micro-level measurement is limited to survey data collected by the study team. Third, most studies did not assess the size of DD but rather characterized DD based on the relative size of the ICT Development Index. The present study intends to supplement existing research on DD measurement and investigate the determinants contributing to DD. Therefore, this study constructs a new, comprehensive framework to examine the connotation, measurement, decomposition, and determinants of the DD.

Given the above limitations, the contributions of this study are as follows. First, this study constructs a new framework with a five-dimensional comprehensive index system and enriches the connotation of DD. The Internet or the ICT industry cannot fully cover the evolution of digital technology and its impact on traditional industries. This study defines DD as the spatial imbalance of the digital economy. The new framework defined in this paper includes multiple levels, such as digital manufacturing, services, technology application, factor transformation, and efficiency improvement, and incorporates new digital technologies, such as artificial intelligence. Second, this study expands the measurement boundary of DD. Measuring the DD at the national level can obscure regional disparities within the country, hindering the inclusive development of the digital economy [19]. Furthermore, small-scale survey data used to quantify DD at the individual level may provide skewed results owing to unrepresentative samples, and such measurements do not accurately reflect the current state of DD at the macro level. Examining the spatial disparities in digital economy growth can aid in providing additional targeted assistance to disadvantaged areas and encouraging coordinated regional development. Therefore, this study measures the degree of China's "national–regional–provincial" DD to reflect this spatial difference. Third, this study enriches the measurement of DD. Studies have primarily relied on direct contrast of the relative size of the ICT Development Index or the relative level of Internet use skills to determine the extent of DD [10,12,15]. Furthermore, some research showed the spatial distribution of ICT development indices, therefore characterizing regional differences in digital economy development. However, none of the abovementioned measures can directly characterize the extent of DD. Only a handful of studies have used the relative rates and Gini indices to measure DD by the degree of imbalanced development of the ICT industry [20,21]. However, such methods do not sensitively capture the impact of the digital economy's fluctuations on measurement results. Therefore, this study seeks to quantify DD using the generalized entropy index and further decompose the measurement results at the regional and provincial levels. The decomposability at different levels cannot be achieved by other methods. Fourth, the relevant factors that may influence the formation of DD are thoroughly investigated. Past studies have primarily focused on one dimension of DD, such as the economic [22,23] and social dimensions [9]. However, this study attempts to comprehensively examine the determinants of DD in terms of physical, human, and social capital so policymakers can be greatly targeted to bridge the DD. This provides a policy basis for policymakers to continuously narrow the DD by controlling relevant economic and social factors.

This study defines DD as the degree of spatial imbalance in the development of the digital economy and applies measurement methods in the field of income distribution to the measurement and decomposition of DD (national, regional, and provincial) within China. Furthermore, the determinants of DD are examined from three dimensions of capital: physical, human, and social. The remainder of this paper is organized as follows: Section 2 presents a comprehensive literature review by introducing the connotation, measurement methods, and causes of DD; Section 3 describes the research methodology and data; Section 4 measures and decomposes DD using the generalized entropy index, which is based on data at the city-level; Section 5 investigates the factors that influenced DD; Section 6 discusses our findings; and Section 7 concludes the study and proposes policy implications.

2. Literature Review

2.1. Connotation of DD

DD, also regarded as digital inequality by certain scholars [24], can be traced back to Alvin Toffler's 1990 book Power Shift. However, this book does not directly define DD but only mentions concepts such as the "information gap." Subsequently, the issue of the "information and technology divide" began to attract widespread attention globally, particularly in Europe and the United States. Lloyd Morrisett, the president of the Markle Foundation in the United States, first introduced the concept of "digital divide" in 1995 [25]. The National Telecommunications and Information Administration (NTIA) published four reports on DD under the main title "Falling through the Net" from 1995 to 2000, with subtitles "A Survey of the 'Have Nots' in Rural and Urban America" (1995), "New Data on the Digital Divide" (1997), "Defining the Digital Divide" (1999), and "Toward Digital Inclusion" (2000), which provided a brand-new definition of DD. In July 1999, the United States issued the official document Bridging the Digital Divide: Defining the Digital Divide, representing the beginning of a comprehensive study of the DD phenomenon. The Okinawa Charter on Global Information Society, adopted at the G8 Summit meeting in Japan in July 2000, highlighted that a large DD exists between developed and developing countries concerning the development of information technology and focused on how to bridge the DD. This was the first time that the issue of DD had appeared in an official document of an international organization. In November 2000, China held a high-level symposium on "Crossing the Digital Divide" in Beijing and conducted in-depth discussions on the nature of DD and strategies to address it. Since then, there has been a worldwide boom in research on DD.

Most of the present studies define DD in terms of the residents' ability to use ICT. For example, according to the OECD, DD denotes the disparity in access to and use of ICT among individuals, households, businesses, and geographic areas at different socioeconomic levels. With the continuous development of ICT and its applications, the connotation of DD has been enriched. According to the existing research, DD is roughly divided into three stages, namely the first-, second-, and third-level DD.

(1) The first-level DD spans around 1995 to 2000 and refers to inequalities in the "accessibility" of Internet technologies across regions and groups [6,26]. DD became one of the focuses of academic research in the mid-1990s. Along with the rapid increase in Internet access and personal computer use, the proportion of the population with Internet access has increased in developed countries with faster ICT development. The first-level DD is no longer a major impediment to the development of the digital economy in developed countries. However, in countries or regions lagging in ICT, such as Africa, most of the population continues to be "information poor". Low Internet availability is one of the major constraints to economic development [27].

(2) The second-level DD spans from 2001 to 2010 and specifically refers to the differences in Internet skills between different regions and groups [28]; it is thus also known as the "skills divide." According to van Deursen and van Dijk, even after a country or region's Internet penetration rate reaches saturation, the problem of DD internally keeps worsening. Therefore, the focus of DD research has switched from Internet access to Internet skills, and disparities in Internet skills are related to not only ICT infrastructure penetration but also users' physical, human, or social capital [29].

(3) The third-level DD spans roughly from 2010 to the present. Existing research has defined the three levels of DD in slightly various ways. However, it is now most identified by the scale of the benefits of Internet skills [7,30]. For example, the general population is separated into "advantaged" and "disadvantaged" in their use of Internet abilities, with both groups having equal access to and use of the Internet. However, owing to determinants such as income and education, the "advantaged" are likely to use the Internet for study or employment, whereas the "disadvantaged" are likely to use the Internet for dating or pleasure. Among them, the "advantaged" who use the Internet for labor production typically benefit more than the "disadvantaged" who use the Internet for leisure and enjoyment, resulting in a third-level DD.

2.2. Measurement of DD

The current statistical framework for DD is not yet well developed, and most existing statistical practices use indicators related to ICT access and use, such as percentage of households with Internet access, percentage of households with computers, international Internet bandwidth per Internet user [10], Internet browsing, communication, email, blogging, online streaming, and social networking [31,32]. Related studies have mostly measured the first- and second-level DD, with limited focus on the third level. There are three existing methodologies for measuring DD: ICT index, econometric modeling, and inequality indicators.

2.2.1. ICT Index

The ICT index is a widely used method in current DD measurement. Its mechanism involves examining the indicators that can represent the level of ICT development and group differences, constructing the corresponding ICT index, and intuitively measuring the size of DD by ranking the relative positions of ICT indices of different regions and groups. This index is further classified into single- and composite-index methods based on the number and comprehensiveness of the indicators in the evaluation system. In the early days of digital technology development, researchers' understanding of DD focused on the differences in access to computers and the Internet. For example, Selhofer and Hüsing [33] used the percentage of the population without ICT access to estimate the magnitude of DD.

However, a single index cannot comprehensively and systematically portray the scope of DD. Along with the development of ICT and the continuous enrichment of digital media forms, relevant organizations and scholars tend to use the comprehensive index method (or multivariate statistical method) to portray DD systematically. For example, Katz et al. [34] used survey data from 150 countries between 2004 and 2010 to construct a comprehensive evaluation index of digital proficiency by selecting 23 relevant indicators, which are from six dimensions of ICT affordability, ICT infrastructure, Internet access, Internet usage, Internet skills, and human capital, including telecommunication investment per capita, Internet coverage, and percentage of individuals who use the Internet for socializing and others. ITU published the "ICT Development Index (IDI)" in its report Measuring the Development of the Information Society, which comprises three dimensions: ICT access, ICT usage, and ICT skills. This report specifically includes 11 indicators, such as fixed-telephone subscriptions per 100 inhabitants, percentage of individuals using the Internet, mean years of schooling, and so on. The relative ranking among countries or regions through the IDI index proposed by the ITU allows for an intuitive analysis of the global or regional DD. The European Commission [35] also published the Digital Economy and Society Index (DESI), which compared regional differences in digitization levels across four dimensions: human capital, connectivity, integration of digital technology, and digital public services. Bruno et al. [12] employed correlation analysis and principal component analysis to streamline the DESI and utilized the simplified index to assess the digital divide in EU countries.

2.2.2. Econometric Model

DD includes disparities in opportunity to benefit from ICT usage and inequalities in ICT access and use. Some researchers employed quantile regression modeling to investigate the inequality in access to ICT benefits. Individuals' economic and social performance differ at varying levels of DD. Moreover, the quantile regression method can reflect the degree of heterogeneity in the economic and social performance of regions or groups at different digitization levels. Scholars have used the extent of such heterogeneity as a characterization of DD [36,37]. Furthermore, some researchers have noticed the impact of space on the development of digital technology and used spatial econometric models to measure DD. The specific step is to characterize DD through geographic distribution differences using indicators such as the Moran index to illustrate the spatial distribution of digital development in a region [38,39]. This case is a further demonstration of the ICT index method at the spatial level, where a uniform spatial distribution indicates a small degree of DD.

2.2.3. Inequality Indicators

The ICT index method can be used to analyze the extent of DD between different regions and groups by comparing the relative rankings of ICT development levels. Moreover, the econometric modeling method can be used to obtain differences in the impact of digital technology on different groups through regression results and to investigate differences in the development of regional digitization levels using spatial distribution. However, the two approaches are insufficiently detailed and do not explicitly depict the size of DD through numerical values. Therefore, some scholars have also proposed the idea of directly adopting inequality indicators to measure the extent of DD. The inequality indicator approach specifically includes the relative gap [40], time distance [41], relative rates, and the Gini index [21]. Taking the Gini coefficient method as an example, relevant research has measured the regional digital technology development level and calculated the digital Gini coefficient on this basis to represent DD. As the digital Gini index increases, the degree of DD in the region also increases. A limitation of the approach is the lack of digital technology statistics, with most studies only able to examine DD using data at the national or provincial/state level [19,42]. Moreover, granular data, such as at the city, district, and county levels, are lacking. This case may conceal gaps in digital technology development among detailed regions, which is not conducive to a targeted approach to bridging DD.

2.3. Determinants of DD

The determinants of DD come from the various inequalities prevalent within societies, such as income and consumption inequalities, which are part of economic differences, and education inequality, which is part of social or life opportunity differences [43]. Inherent inequalities in society can lead to unequal resource distribution, which can lead to unequal access to and usage of digital technology and the establishment of a DD across different areas and groups [44]. Overall, the core causes of DD include differences in physical, human, and social capital.

2.3.1. Differences in Physical Capital

The major factor determining the DD is the "economic divide" [45–47]. Differences in economic development contribute to disparities in resource availability and living standards among areas and groups, which affects access to and utilization of digital technology and results in an uneven distribution of digital technology. Differences in physical capital manifest as differences in the degree of economic development at the macro level [45] and as differences in household income at the micro level [46,47]. However, notably, DD based on differences in physical capital decreases owing to the low cost of Internet access and use, including the growing impact of ICT coverage and penetration on lower-income "disadvantaged" groups [48].

2.3.2. Differences in Human Capital

Human capital determinants mainly comprise the group's education, age, and gender differences. (1) Determinant of education. The most significant factor contributing to DD is the level of education, with literate regions being likely to have high ICT penetration rates [49–52]. DD is impacted by disparities in the level of education in two ways. On the one hand, if the residents are educated, their exposure to digital technology and competency in Internet abilities is high, putting them at an advantage in the DD [53]. On the other hand, highly trained and educated workers are inclined to gather in cities because metropolitan telecommunication infrastructures are typically better, and the cost of building new infrastructures is low, allowing them to acquire Internet skills easily and experience the information benefits of the digital age [54]. (2) Determinant of age. Generally, older adults are more likely to be at a "disadvantage" in the DD than younger individuals [55,56]. Simultaneously, research has revealed that DD exists between young and old, and older adults have apparent Internet skills disparity, commonly known as the "gray divide" [57]. Poor Internet capabilities among older adults can be explained by a lack of technical Internet equipment, such as personal computers and cell phones. Moreover, motivation to use the Internet is lacking among older adults, such as the opinion that Internet information is useless or has little importance to one's life and health [58]. (3) Determinant of gender. The "gender divide" is another significant expression of DD. The gender DD may impede women from benefiting equally from the technology revolution as men and may place women at a disadvantage regarding learning using computers [59].

2.3.3. Differences in Social Capital

DD is a multidimensional problem, and an uneven distribution of social capital, including social and cultural disparities among regions, may affect the formation of DD [54]. Specifically, social capital factors include family, neighborhood, community, and other organizations or groups' perceptions and attitudes toward digital life, intra-group communication, and interaction on online platforms. Urban individuals typically have low social costs of using the Internet and are likely to acquire Internet skills because they can learn how to use the Internet more easily from their neighbors [60].

2.4. Summary

In general, studies have explored the measurement of DD and its determinants to some extent, but some limitations still exist. First, systematic research on measuring DD is scarce, particularly in-depth measurement of DD at the regional and provincial levels. Second, most of the recent research has generally portrayed the magnitude of DD through distributional disparities in spatial digitization levels rather than making specific measurements of DD. Third, the causes impacting DD have numerous dimensions, and most research may be biased by investigating only one-dimensional elements influencing DD. Therefore, this study measures DD at the national, regional, and provincial levels and uses the inequality index method to measure DD based on city-level data. Furthermore, this study classifies DD at the regional and provincial levels and investigates its determinants, including physical, human, and social capital. Notably, the basic data used in this study is a digital index at the city level, but no official and definitive statistical framework exists for measuring the digital index. The Statistical Classification of the Digital Economy and Its Core Industries (2021), released by the National Bureau of Statistics of China in 2021, establishes the official scope of digital economy measurement. Considering that the digital economy can appropriately represent digital development, this study replaces the digitization level index with the digital economy index as the base data to measure DD, which characterizes the unevenness of spatial digital economy development.

3. Methodology and Data

3.1. Methodology

3.1.1. A New Framework for the DD

In this study, the DD primarily assesses the extent of the unbalanced development of the digital economy. Consequently, the measurement of the DD index should be grounded in the digital economy development index. The national economic accounting method by Barefoot et al. [2] and the comprehensive evaluation method by ITU [10] are the two primary statistical measurement methods used to measure the digital economy. However, the national economic accounting method has limitations, such as an uncertain measurement boundary, an immature statistical method, and weak basic data. Additionally, given the setting of the digital economy's quick development, including the rapid upgrading and iteration of digital technology, applying national economic accounting methodologies to measure the digital economy may have additional statistical inaccuracies. This study uses a comprehensive evaluation methodology to measure the digital economy index, which can incorporate the most recent digital technology, such as industrial Internet, artificial intelligence, and e-commerce, into the evaluation system by setting up additional systematic and comprehensive evaluation indices. The use of this method can reduce the bias of statistical accounting and accurately reflect the current state and trend of the digital economy development. Furthermore, the digital economy index measured by this method is time-continuous, rapid, and spatially comparable [10,35]. Finally, this study employs the generalized entropy method to measure the DD index based on the calculated digital economy development index.

This study uses the standard in Statistical Classification of the Digital Economy and Its Core Industries (2021) to build a comprehensive evaluation system based on the following five dimensions: digital product manufacturing, digital product service, digital technology application, digital-driven elements, and digital efficiency improvement. Given the data availability constraints, current databases do not completely cover all subcategories of indicators in the five dimensions. This study refers to related literature and uses available indicators to construct a comprehensive evaluation system for the DD based on the principles of connotation accuracy, data availability, and time continuity (Table 1).

Table 1. A five-dimensional comprehensive index system for the DD.

	First-Level Indicator	Second-Level Indicator	Third-Level Indicator
Digital economy index ↓ Digital divide index	Digital product manufacturing	Digital manufacturing industry development	Percentage of total business revenue in the electronic information industry
			Percentage of the number of enterprises in the electronic information industry
		Digital manufacturing capabilities	Production of integrated circuits per electronic information manufacturing enterprise
			Production of microcomputers per electronic information manufacturing enterprise
			Production of mobile phones per electronic information manufacturing enterprise
			Production of SPC digital switch per electronic information manufacturing enterprise
	Digital product service	Digital service industry development	Percentage of value added in the software and IT services industry
			Percentage of employment in software and IT services industry
			Percentage of employment in the postal industry
		Digital service capabilities	Revenue from software products per capita
			Revenue from IT services per capita
			Revenue from embedded systems software per capita
			Number of postal branches per capita
	Digital technology application	Digital communication technology	Total telecommunication services per capita
			Length of long-distance optical cable per unit area
		Digital platform construction	Mobile phone penetration rate
			Number of websites per 100 individuals
			Number of domain names per 100 individuals
			Number of Internet users per 100 individuals
	Digital-driven elements	Digital-driven infrastructure	Number of mobile phone base stations per capita
			Internet broadband access ports per capita
		Digital-driven media industry	Number of e-publications per capita
		Digital-driven enterprise informatization	Number of computers per 100 individuals
			Number of websites per 100 enterprises
		Digital-driven wholesale and retail industry	Number of e-commerce transactions per e-commerce business enterprise
			Percentage of firms with e-commerce activities
		Digital-driven payment business	Digital payment index
	Digital efficiency improvement	Digital innovation capability	Percentage of R&D expenditure
		Intelligent manufacturing	Percentage of industrial Internet patents granted
		Digital commerce	Percentage of e-commerce patents granted
		High-speed communication	Percentage of 5G patents granted
		Digital finance	Digital insurance index
		Convergence development	"Informatization and industrialization" convergence index

(1) The dimension of digital product manufacturing mainly includes digital manufacturing industry development and digital manufacturing capabilities. The former is

represented by the proportion of total operating income and the number of enterprises in the electronic information industry. As the value of the related indicator increases, the digital manufacturing industry's development scale also increases. The latter is defined by the average production of integrated circuits, microcomputers, mobile phones, and stored program control (SPC) digital switches per electronic information enterprise. The corresponding indicators portray the production capacity of digital manufacturing enterprises and are important for characterizing the intermediate and final products of digital manufacturing.

(2) The dimension of digital product service mainly includes digital service industry development and digital service capabilities. The former is characterized by the percentage of value added in the software and IT services industry, the percentage of employment in the software and IT services industry, and the percentage of employment in the postal industry. As the value of the corresponding indicator increases, the scale of the digital services industry also increases. The latter is characterized by revenue from software products, IT services, and embedded systems software per capita, including the number of postal branches per capita. The corresponding indicators portray the service capacity of digital technology and digital products, including the inclusiveness of postal services for the residents, respectively.

(3) The dimension of digital technology application mainly includes digital communication technology and digital platform construction. The former is defined by the total telecommunication services per capita and the length of long-distance optical cable per unit area. The total telecommunication service per capita reflects the penetration and usage of digital communication technology by the residents. The length of long-distance optical cable per unit area represents the region's level of communication facility development. Both represent the infrastructure and use of digital communication technology. The latter is characterized by the mobile phone penetration rate, number of websites per 100 individuals, number of domain names per 100 individuals, and number of Internet users per 100 individuals. The Internet is an important foundation and a major platform for digital economy development. The above four indicators portray the entire construction process of a digital platform from the multidimensional perspective of Internet access, platform construction, and residents' usage.

(4) The dimension of digital-driven elements includes digital-driven infrastructure, media industry, enterprise informatization, wholesale and retail industry, and payment business. Digital-driven infrastructure is represented by the number of mobile phone base stations per capita and Internet broadband access connectors per capita, reflecting the development level of digital infrastructure. The digital-driven media industry is represented by the number of e-publications per capita, indicating the digitization level of the regional media industry. Digital-driven enterprise informatization expresses the level of regional enterprise informatization through the two dimensions of digital equipment ownership and digital platform establishment, specifically using the number of computers per 100 individuals and the number of websites per 100 enterprises. The digital-driven wholesale and retail industry uses the number of e-commerce transactions per e-commerce business enterprise and the percentage of firms with e-commerce activities to express the level of digital-driven wholesale and retail in the region through the wholesale and retail activities of goods carried out on Internet-based e-commerce platforms. The digital-driven payment business, characterized by the "Payment Index" of the Peking University Digital Financial Inclusion Index, is primarily defined by the number of payments per capita and the ratio of high-frequency (50 or more times per year) active users to users who use the Alipay App once or more per year. The shift in payment methods from cash and credit cards to online electronic payments is an important manifestation of digital technology drive. As the "Payment Index" increases, the driving effect of digital technology on the shift in the means of payment also increases.

(5) The dimension of digital efficiency improvement mainly includes digital innovation capability, intelligent manufacturing, digital commerce, high-speed communication, digital finance, and convergence development. Digital innovation capacity is characterized by the percentage of R&D expenditure. The basis of industrial digitization is the continuous innovation of digital science and technology. Therefore, the percentage of R&D expenditure is used to characterize investment in science and technology innovation and innovation capacity. Intelligent manufacturing, a new industry that combines traditional manufacturing with intelligent and automation technology, is indicated as a percentage of industrial Internet patents granted. Industrial Internet is a crucial technical tool for promoting the smart manufacturing process. The percentage of industrial Internet patents granted is an important indicator of smart manufacturing development and innovation. Digital commerce is indicated as a percentage of e-commerce patents granted and realizes the organic integration of digital technology and traditional commerce activities, which include wholesale and retail of goods, transportation and logistics, accommodation, food and beverage, leasing, and business services. The percentage of e-commerce patents granted is an important indicator of digital commerce development and innovation. High-speed communication is expressed by the percentage of 5G patents granted. 5G communication technology is the most recent generation of broadband mobile communication technology, which can achieve human-machine-object interconnection and interoperability. Therefore, it has the potential to accelerate the development of next-generation digital technologies, such as the Internet of Things and artificial intelligence, including the rapid merger of traditional sectors and the digital economy. The percentage of 5G patents granted reflects the regional level of high-speed communication technology. Digital finance is characterized by the "Insurance Index" in the Peking University Digital Financial Inclusion Index, which comprises the number of insurance users per 10,000 Alipay users, the number of insurances per capita, and the amount of insurance per capita. Digital finance reflects the organic integration of digital technology with financial markets, including the effective promotion of traditional financial efficiency. Convergence development is characterized by the "informatization and industrialization" convergence index in the report Assessment of China's Informatization and Industrialization Convergence Development Level by the Ministry of Industry and Information Technology. The continuous development of digital technology encourages informatization and industrialization to coexist and increases the effectiveness of industrial production and innovation. Therefore, the index measures the level of informatization and industrialization integration.

3.1.2. Measurement of the Digital Economy Index

Previous research has indicated that the omission of appropriate weighting of indicators within a complete evaluation technique can potentially influence the results of measurements [61–63]. Hence, the present study employs the entropy weight method (EWM) to allocate weights to sub-indicators in the comprehensive assessment index system of the digital economy. The EWM is a quantitative approach that uses objective criteria to allocate weights to various indicators. These weights are determined by analyzing the inherent fluctuation features of the data, therefore mitigating the potential influence of subjective evaluations on measurement outcomes. The mechanism employed by EWM involves quantifying the level of dispersion through the evaluation of the entropy value associated with the indicator. A lower entropy number indicates a higher level of dispersion, resulting in a stronger emphasis on the indicator's contribution to the upper level it is associated with. The sequential procedures are outlined as follows. In the context of the

k-th subject, it is postulated that the j-th third-level indicator is equivalent to x_{kj}. The initial step involves employing the critical value approach to normalize the indicators.

$$x'_{kj} = \frac{x_{kj} - min(x_j)}{max(x_j) - min(x_j)} \text{or} x'_{kj} = \frac{max(x_j) - x_{kj}}{max(x_j) - min(x_j)}. \tag{1}$$

Since all the indicators in the comprehensive evaluation system of the digital economy are positive, the above formula is used to normalize the indicators, where $max(x_j)$ and $min(x_j)$ represent the highest and lowest values of the j-th third-level indicator in the sample interval, respectively. The weight of the j-th third-level indicator can be computed for the k-th region.

$$y_{kj} = \frac{x'_{kj}}{\sum_{k=1}^{m} x'_{kj}}. \tag{2}$$

where m is the number of subjects and the information entropy e_j of the j-th third-level indicator is represented as:

$$e_j = -K\sum_{k=1}^{m}\left(y_{kj}\ln y_{kj}\right). \tag{3}$$

where $K = 1/\ln m$ is a constant, and n represents the number of third-level indicators. The entropy weight ω_j of the j-th third-level indicator can be represented as:

$$\omega_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)}. \tag{4}$$

Therefore, the DEI_{ki}, which donates the k-th subject's i-th second-level indicator in the digital economy comprehensive assessment system, can be represented as:

$$DEI_{ki} = \sum_{j=1}^{n_i}\left(\omega_{ij} Z_{kij}\right). \tag{5}$$

where ω_{ij} represents the entropy weight of the j-th third-level indicator in the i-th second-level indicator, Z_{kij} represents the value of each third-level indicator after normalization of the k-th subject and n_i represents the number of third-level indicators included in the i-th second-level indicator. Repeating the above steps ((1) to (5)), the digital economy development index DEI_k of the k-th subject can be represented:

$$DEI_k = \sum_{i=1}^{N}(W_i DEI_{ki}). \tag{6}$$

where W_i represents the entropy weight of the i-th second-level indicator under the first-level indicator, and N is the number of second-level indicators in the comprehensive evaluation system of the digital economy. The value of DEI_k is bounded between 0 and 1, with higher values indicating a greater level of growth in the digital economy for the k-th subject.

It is important to acknowledge that the data presented in Table 1 are solely accessible at the city level for the digital finance index, the number of Internet users per 100 individuals, the percentage of employment in the software and IT services industry, and the total telecommunication services per capita. Conversely, the remaining indicators are available up to the provincial level. Therefore, the initial stage involves evaluating the extent of digital economy advancement in the 31 provinces, autonomous regions, and municipalities (excluding Hong Kong, Macao, and Taiwan). This evaluation is conducted by the utilization of the complete assessment index system outlined in Table 1. The last phase involves assessing the level of ICT development in various cities by employing the EWM and utilizing the aforementioned data about ICT at the city level. The third phase involves the computation of the city's proportionate contribution to the advancement of ICT for each year within the respective province. The ultimate stage is the multiplication of the city's portion of ICT development by the index of provincial digital economy development.

By following the aforementioned procedures, it is possible to derive the digital economy development index for each city. The precise calculating formula is as follows.

$$DEI\_CITY_{ij} = DEI_i \times \frac{DEI_{ij}}{\sum_{j=1}^{N_i} DEI_{ij}} \times N_i. \quad (7)$$

The equation provided above defines the variable DEI_CITY_{ij} as the digital economy development index of the j-th city in the i-th province. DEI_i represents the digital economy development index of the i-th province. DEI_{ij} represents the ICT Development Index of the j-th city in the i-th province. N_i represents the number of cities included in the i-th province. $DEI_{ij}/\sum_{j=1}^{N_i} DEI_{ij}$ represents the proportion of the digital economy in the j-th city within the i-th province. The level of the digital economy in the linked city within the relevant province is directly proportional to the value of this indicator. The role of cities in the advancement of the digital economy is becoming increasingly crucial as they continue to acquire a larger share of digital resources. In addition, the equation incorporates the variable N_i, denoting the count of cities within provinces to mitigate the impact of dimensionality and minimize computation mistakes arising from variations in the number of cities across various provinces.

3.1.3. Measurement and Decomposition of the DD Index

The DD can be understood as a representation of the unequal development of the digital economy, wherein a higher degree of balance in digital economy development corresponds to a lower level of the DD. The measurement of the DD in this study employed the generalized entropy index derived from the domain of income distribution. There are several justifications for choosing this particular method. First, it possesses the capability to accurately quantify the DD and examine its temporal patterns. Furthermore, this methodology has a high degree of sensitivity in accurately capturing fluctuations in the degree of advancement within the upper and lower extremities of the digital economy. Moreover, the methodology employed is decomposable, enabling the assessment of contributions made by different regions or provinces towards the observed fluctuations in the DD.

The Theil index and MLD index are two fundamental types of generalized entropy indexes. The utilization of the generalized entropy index originated in the field of information theory and subsequently found application in the realm of economics, where it serves as a tool for evaluating inequality. The generalized entropy index not only takes into account the distribution form of the sample but also allows for the decomposition of imbalance to assess the heterogeneity of contribution rates. Let us consider regions of China as a case study. Assuming N represents the total number of regions, DE_i represents the comprehensive level of digital economy development in the i-th region, $\overline{DE}$ represents the average digital economy development across all regions, and α represents the model parameter, the measurement of DD using the generalized entropy index method can be mathematically expressed.

$$DD\_GE = \frac{1}{N\alpha(\alpha - 1)} \sum_{i=1}^{N} \left[\left(\frac{DE_i}{\overline{DE}} \right)^{\alpha} - 1 \right]. \quad (8)$$

In addition, the parameter α in the model plays a crucial role in determining the distinct sensitivity characteristics of the generalized entropy index concerning the overall distribution. The sensitivity of the generalized entropy index to the higher tail of the distribution increases as the parameter α increases, whereas the sensitivity to the lower tail of the distribution increases as the parameter α decreases. In general, the variable α is assigned a value of either 0 or 1. The specific type of generalized entropy index is determined by varying values of α. When the parameter α is set to 1, the generalized entropy index can be denoted as the Theil index in the above expression.

$$DD\_THEIL = \frac{1}{N}\sum_{i=1}^{N} \frac{DE_i}{\overline{DE}} \ln\left(\frac{DE_i}{\overline{DE}}\right). \tag{9}$$

When α is equal to 0, the generalized entropy index can be denoted as the Theil index in the above expression.

$$DD\_MLD = \frac{1}{N}\sum_{i=1}^{N} \ln\left(\frac{\overline{DE}}{DE_i}\right). \tag{10}$$

The Theil and the MLD index represent inequality measures that are sensitive to the upper tail and lower tail distributions, respectively. Due to the large differences in development between regions in China (the economic level in the eastern region is higher, while that in the central and western regions is relatively lower), both methods should be used in measurement to avoid the impact of large changes in the level of digital economy development in a certain region on the measurement results. In addition, the measurement of the two indices can also be compared with each other to verify the robustness of the results.

Compared to other indicators that reflect the degree of imbalance, the advantage of the generalized entropy index resides in its decomposability. This study seeks to break down the estimated generalized entropy index at the regional or provincial level and further evaluate the contribution rate of intra-regional (intra-provincial) and inter-regional (inter-provincial) imbalance to overall imbalance. Take the region as an example. The decomposition formula for the Theil index and MLD index is as follows.

$$DD\_THEIL = \sum_{j}\left(\frac{DE_j}{DE}\right) DD\_THEIL_j + \sum_{j} \frac{DE_j}{DE} \ln\left(\frac{DE_j/DE}{N_j/N}\right). \tag{11}$$

$$DD\_MLD = \sum_{j}\left(\frac{N_j}{N}\right) DD\_MLD_j + \sum_{j} \frac{N_j}{N} \ln\left(\frac{N_j/N}{DE_j/DE}\right). \tag{12}$$

Both the overall Theil index and MLD index may be divided into two components: intra-regional inequality and inter-regional inequality. In Equations (11) and (12), the first term on the right side represents intra-regional inequality, and the second term represents inter-regional inequality. Furthermore, DE represents the comprehensive index of the level of development in the digital economy across all regions. DE_j represents the level of development in the digital economy specifically for the *j*-th region. N represents the total number of cities. N_j represents the number of cities included in the *j*-th region. DD_THEIL_j and DD_MLD_j represent the Theil index and MLD index within the *j*-th region, respectively.

3.1.4. Determinants of DD

The determinants of DD can be categorized into three distinct groups: physical capital, human capital, and social capital. The analysis of influencing factors includes correlation analysis, factor analysis, regression analysis, etc. Among them, the correlation analysis can only examine the simple correlation between two variables and fails to consider the impact of covariates. The factor analysis integrates potential influencing factors into different factors, and its results are statistically significant but lack economic significance. The regression analysis can take into account the impact of covariates, and its results also have strong economic significance. Therefore, this study presents a two-way fixed-effects multiple regression model derived from the aforementioned information. The precise configuration of the model is as follows.

$$DD_{i,t} = \alpha + \beta PHY\_CAP_{i,t} + \gamma LAB\_CAP_{i,t} + \psi SOC\_CAP_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}. \quad (13)$$

In the given equation, $DD_{i,t}$ denotes the provincial-level DD, encompassing the Theil index $DD\_THEIL_{i,t}$ and MLD index $DD\_MLD_{i,t}$. $PHY\_CAP_{i,t}$ denotes the factors that influence physical capital, such as economic growth, infrastructure, industrial structure, foreign trade, and fiscal revenue. $LAB\_CAP_{i,t}$ denotes the factors that contribute to human capital, such as education, age, and innovation capacity. $SOC\_CAP_{i,t}$ denotes the factors that contribute to social capital, encompassing offline social organizations, online communication, and interaction. μ_i and λ_t denote the fixed effects associated with province and year, respectively. The two, respectively, represent the control of difficult-to-observe variables that do not change with time but only change with the province and do not change with the province but only change with time. The symbol $\varepsilon_{i,t}$ denotes the error term.

3.2. Data and Variables

3.2.1. Data

The primary data sources used in this research include the "China Statistical Yearbook", "China Urban Statistical Yearbook", provincial statistical yearbooks, "China Information Industry Yearbook", "China Electronic Information Industry Statistical Yearbook", "China Information Yearbook", the CNNIC, the "Digital Inclusive Finance Index" jointly released by Peking University and Ant Financial Services, the special database of the "Enterprise Research Big Data" platform, the report of the Ministry of Industry and Information Technology on the evaluation of the integration and development level of China's informatization and industrialization, and the China Economic and Technological Database. The obtained data have extremely few missing values, which are uniformly filled using the linear interpolation approach.

The digital economy index is calculated using macro data from 298 cities across 31 provinces, autonomous regions, and municipalities from 2010 to 2020. These 298 cities are all prefecture-level cities in China, collectively accounting for over 95% of the country's GDP, rendering the sample highly representative. Owing to the lack of indicators related to the digital economy in various districts and counties within the municipality, measuring DD within the municipality is difficult. Therefore, when assessing the provincial DD, this study excludes samples from municipalities. Notably, 2010 was chosen as the starting date of this study for the following reasons: (1) The growth of the digital economy depends on the Internet speed and popularity of intelligent devices. According to the official website of the Ministry of Industry and Information Technology, on 7 January 2009, the Ministry of Industry and Information Technology issued three third-generation mobile communication (3G) licenses to China Mobile Communications Group, China Telecom Group Corporation, and China United Network Communications Co., Ltd., Beijing, China, marking China's official entry into the 3G era. Additionally, since 2010, the use of smart devices, such as smartphones, has steadily increased in China. Before 2010, intelligent devices were neither widespread nor was digital technology organically integrated with economic development and penetrated social production, which did not meet the current definition of the digital economy. (2) Owing to the limitations of the original database, most of the indicators selected in the comprehensive evaluation system of the digital economy constructed in this study are missing data before 2010. Moreover, some dimensions of digital economy development only appear after 2010. Furthermore, considering that most of the ICT-related data in the past two years are currently unavailable, this study selects 2020 as the last year of the research interval. Studying the changes in DD between 2010 and 2020 is meaningful, covering the rapid development stage of China's digital economy.

3.2.2. Dependent Variable

As the dependent variable, DD is mainly measured at the national, regional, and provincial levels. This study uses the generalized entropy index method, including the Theil and mean log deviation (MLD) indices, to measure DD. The two indices portray the two kinds of results that are sensitive to the upper- and lower-tailed changes, respectively. Table 2 shows the measurement results of the provincial-level DD.

Table 2. Descriptive statistics of main variables.

Variable	Mean	Std	Min	Max	Obs.
DD (Theil Index)	0.1530	0.1471	0.0075	0.8162	297
DD (MLD Index)	0.2280	0.3160	0.0077	1.8014	297
Economic Growth	10.6893	0.4004	9.4818	11.7249	297
Industrial Structure	0.4453	0.0679	0.2862	0.6039	297
Infrastructure	0.8118	0.4651	0.0495	1.8649	297
Foreign Trade	0.0315	0.0343	0.0010	0.2051	297
Fiscal Revenue	0.1026	0.0211	0.0578	0.1695	297
Aging	9.9705	2.4609	4.8244	17.4154	297
Education	0.0164	0.0057	0.0051	0.0335	297
Innovation	14.4783	16.9143	0.5400	84.8931	297
Social Organization	4.8751	2.1157	1.1122	12.0214	297
Online Interaction	7.5945	0.8701	6.3223	9.5446	297

3.2.3. Independent Variables

(1) Economic growth: using per capita gross domestic product (GDP) as the proxy variable and performing logarithmic processing. (2) Industrial structure: represented by the proportion of the added value of the tertiary industry in GDP. (3) Infrastructure: represented by the number of highway kilometers per unit area. (4) Foreign trade: represented by the proportion of total import and export volume of goods to GDP divided by domestic destination and source of goods. (5) Fiscal revenue: represented by the proportion of general budget revenue to GDP. (6) Aging: represented by the proportion of the elderly population aged 65 and above to the total population. (7) Education: represented by the proportion of graduates with a college degree or above (including college, undergraduate, and other higher education degrees) to the total employment. (8) Innovation: represented by the number of patents granted per 10,000 individuals. (9) Social organization: represented by the number of social organizations per 10,000 individuals; as social organizations become highly social, the degree of offline social connection within the group increases. (10) Online interaction: owing to limited data availability, no indicators were found in existing macro data that directly reflect the level of online interaction and communication. This study selects the per capita telecommunications business income to characterize the degree of online social connectivity. As the telecommunications income increases, the frequency of residents' communication and interaction with others (including relatives, friends, colleagues, or strangers) online also increases, including the degree of online social connection.

4. Measurement of DD

4.1. Measurement of Digital Economy Development

The digital economy index serves as the foundational information for assessing DD. This study analyzes the level of imbalance in the development of the digital economy as a representation of DD. The aforementioned method is used in this study to calculate the level of digital economy development in 298 cities in China from 2010 to 2020. Considering length constraints, this study mainly offers the results of the province's digital economy index, as presented in Table 3. First, across the entire sample period, the overall index of China's digital economy increased from 0.0978 to 0.2823, with an average annual growth rate of 18.87%. This result indicated that from 2010 to 2020, with the continuing development of digital technology, China's digital economy has shown a powerful growth tendency, with a reasonably fast yearly growth rate.

Table 3. Changes in the provincial digital economy index from 2010 to 2020.

Province	2010	2020	Average Growth Rate	Province	2010	2020	Average Growth Rate
Nation	0.0978	0.2823	18.87%	Henan	0.0362	0.1859	41.35%
Beijing	0.4135	0.8152	9.71%	Hubei	0.0601	0.2414	30.17%
Tianjin	0.1728	0.3746	11.68%	Hunan	0.0556	0.2183	29.26%
Hebei	0.0487	0.1441	19.59%	Guangdong	0.2689	0.4555	6.94%
Shanxi	0.0613	0.1698	17.70%	Guangxi	0.0386	0.1854	38.03%
Inner Mongolia	0.0206	0.1379	56.94%	Hainan	0.0275	0.1832	56.62%
Liaoning	0.1251	0.2376	8.99%	Chongqing	0.0770	0.4853	53.03%
Jilin	0.0453	0.2006	34.28%	Sichuan	0.0992	0.3487	25.15%
Heilongjiang	0.0481	0.1251	16.01%	Guizhou	0.0406	0.1948	37.98%
Shanghai	0.3441	0.5034	4.63%	Yunnan	0.0329	0.1623	39.33%
Jiangsu	0.3037	0.4566	5.03%	Tibet	0.0234	0.1577	57.39%
Zhejiang	0.1340	0.4345	22.43%	Shaanxi	0.0667	0.2945	34.15%
Anhui	0.0387	0.2325	50.08%	Gansu	0.0543	0.4169	66.78%
Fujian	0.1260	0.3401	16.99%	Qinghai	0.0179	0.1595	79.11%
Jiangxi	0.0399	0.1871	36.89%	Ningxia	0.0199	0.1772	79.05%
Shandong	0.1268	0.3298	16.01%	Xinjiang	0.0645	0.1962	20.42%

Second, the digital economy index for each province in China has shown a stable growth pattern, whereas the overall development of the digital economy exhibits notable spatial variation. The ranking of the digital economy development level is eastern region > central region > western region, whereas the growth rate of the digital economy development is exactly the opposite. The level of digital economy development is particularly high in eastern provinces, such as Beijing, Shanghai, Jiangsu, Guangdong, and Fujian. However, the average annual growth rate of the digital economy index is quite low, with most provinces experiencing growth rates of approximately 10%. The digital economy development level in central provinces, such as Shanxi, Jiangxi, Hubei, and Hunan, is lower than that in eastern regions. However, the average annual growth rate of the digital economy index is generally higher than that of eastern provinces, with most provinces having growth rates between 10% and 50%. Western provinces, such as Tibet, Gansu, Qinghai, and Ningxia, which have a low level of digital economy development, had the highest average annual growth rate of the digital economy index during the research period, with most of them growing at more than 50%. Moreover, a few western regions, such as Guizhou and Yunnan, have an average annual growth rate of the digital economy index close to 40%. From the perspective of spatial heterogeneity in the development of the digital economy, the digital economy is demonstrating a major growth tendency across regions, with the central and western regions expanding quickly and the gap with the eastern regions closing rapidly. The level of national digital economy development inequality has been declining. However, a considerable discrepancy still exists among provinces in the western region, provinces with lower economic development levels in the middle region, and provinces in the eastern region in terms of digital economy development. The unbalanced development of the digital economy may cause regions with higher levels of development to enjoy more benefits from digital technology, such as using digital technology to increase income, promote consumption, and create employment, therefore widening the gap with regions with lower levels of development and increasing the DD.

4.2. Measurement of DD

The measuring of the digital economy development level shows that although the current imbalance in the growth of China's digital economy has decreased, there are still absolute differences in the development of the digital economy between regions. A significant gap exists between the central and western provinces and the eastern provinces. However, the literature on assessing inequalities or imbalances in the development of the digital economy is limited. Hence, this study intends to measure DD from three dimensions: national, regional, and provincial levels. In addition, the weights of the five first-level indicators are 0.2893, 0.2587, 0.2386, 0.1256, and 0.0878, respectively. This shows that the first three indicators representing the foundation of digital technology development have a greater influence, while the last two indicators representing the development of new digital technologies are relatively small. This is also in line with the reality that new digital technologies have not yet been fully popularized and have a low penetration rate.

4.2.1. Results of the National DD

This study uses the Theil and MLD indices in the generalized entropy index to measure the national DD (Figure 2). The degree of the national DD shows a fluctuating downward trend, from 0.4731 in 2010 to 0.2560 in 2020, which is a decrease rate of 45.89%. Digital technologies are characterized by spatial independence, low thresholds, and inclusiveness. The degree of inequality in the national digital economy development is gradually declining, and the digital economy development level among regions is gradually becoming highly balanced as China's Internet infrastructure has continuously improved along with the residents' digital skills.

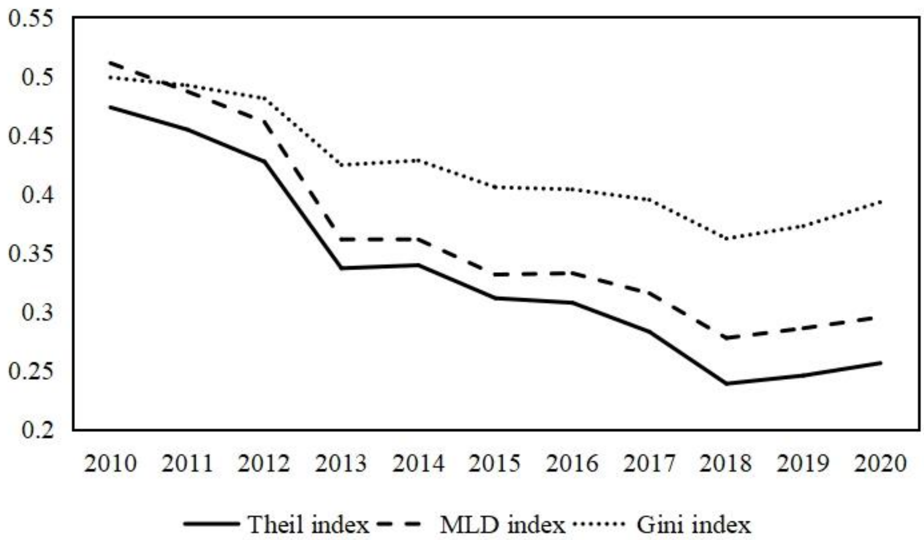

Figure 2. National DD index.

Notably, the degree of DD is increasing in several periods during the entire sample interval. The first period spans from 2013 to 2014. The upward trend of DD could be attributed to the implementation of the "Broadband China" policy in 2013, which is a significant national policy aimed at strengthening digital infrastructure and fiercely expanding the digital economy [64]. During the strategy implementation, some cities were selected as pilot cities, which may increase the level of digital infrastructure construction to some extent between pilot and non-pilot cities in the early stages of implementation, therefore slightly increasing the overall level of DD. However, as various digital economy development strategies are implemented in the later stage, the digital technology spillover effect in places with high degrees of digital economy development is evident. Under its influence, the level of DD has declined. The second period spans from 2018 to 2020. The widening of DD can be ascribed to two aspects. On the one hand, the reason for this is the continuous emergence and popularization of new digital technologies, such as artificial intelligence, big data, cloud computing, e-commerce, and Internet finance, which first benefited cities in the eastern, central, and western regions with developed digital economies. However, cities with low levels of digital economy development have been slow in the field of new digital technology, which potentially widens the digital economy development gap among regions. On the other hand, the impacts of the COVID-19 pandemic at the end of 2019 have limited the flow of people, transportation, and some information. Although this phenomenon has accelerated the growth of some online businesses, the digital economy encompasses various dimensions, including not only online businesses but also offline digital product manufacturing and digital industry services. This case is generally conducive to neither the development of the digital economy nor the spatial spillover effect of cities with high levels of digital economy development to cities with low levels of development, thereby increasing the degree of the national DD to some extent.

Figure 2 shows that the trend of the MLD index, although roughly the same as the Theil index, is slightly larger in absolute terms than the Theil index. One probable explanation is that cities in China with high levels of digital economy development are fewer than those with low development levels. A significant disparity exists in the development of the digital economy among cities, and the sample distribution is skewed to the right. The MLD index is more sensitive to changes in the lower tail sample, whereas the Theil index is more sensitive to changes in the upper tail sample. Owing to the right-skewed distribution of the sample, the calculation results obtained using the Theil index are relatively larger than those obtained using the MLD index. Moreover, the Gini index approach is used to remeasure DD to ensure the robustness of the results (Figure 2). The trend of the change in DD measured by the Gini index is consistent with the results measured based on the generalized entropy index method, which indicates that the results measured in this study are robust.

4.2.2. Results of the Regional DD

This study examines DD within the four major regions (Provinces can be classified into distinct groups based on the level of development in their digital economies and the extent of the digital divide. These groups align with the four major regions designated by the National Bureau of Statistics of China, namely the eastern, central, western, and northeastern regions. The eastern provinces encompass Hebei, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The central provinces encompass the provinces of Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western provinces encompass a number of provinces and autonomous regions, namely Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The Northeast provinces encompass Liaoning, Jilin, and Heilongjiang), as shown in Figure 3. Using the Theil index as an example, from an absolute level, the DD index in the eastern and western regions is higher, with a greater contribution rate to the national DD, whereas that in the central and northeastern regions is lower. The reason for this is that the cities with the highest level of digital economy development are mostly located in the eastern region, which undoubtedly widens the gap between cities with strong digital economy development and those with general development within the eastern region. The cities with low levels of digital economy development mostly belong to the western region, which also widens the gap between cities with poor and better digital economy development within the western region. The level of digital economy development in various cities in the central and northeastern regions is relatively close, and the overall difference is relatively small. In terms of trends, the degree of DD in the eastern, western, and northeastern regions has significant downward tendencies, whereas the center region's DD has not experienced significant variation. For the eastern, western, and northeastern regions, the inclusive features of digital technology and the improvement of digital infrastructure within the region have led to faster growth rates in cities that are relatively underdeveloped. Furthermore, the development gap of the digital economy among cities has been narrowing. The level of digital economy development of cities in the central region does not differ significantly, and the rate of growth of digital economy development is highly stable. Thus, the degree of its DD fluctuates less over the entire sample interval. Furthermore, this study measures the size of DD using the MLD and Gini index approach (Figure A1 in Appendix B). The results are broadly consistent with the Theil index, which proves the robustness of the measurements. Figure A1 also shows that in the eastern region, the Theil index is greater than the MLD index, whereas in the central and western regions, the MLD index is more than the Theil index. The reason for this is that the eastern region has many cities with a high level of digital economy development. Furthermore, compared with the MLD index, the Theil index, which is more sensitive to changes in the upper and lower tails of the sample, is relatively larger. The central and western regions have numerous samples with a less developed digital economy, and the MLD index, which is more sensitive to changes in the lower tail sample, is significantly larger than the Theil index.

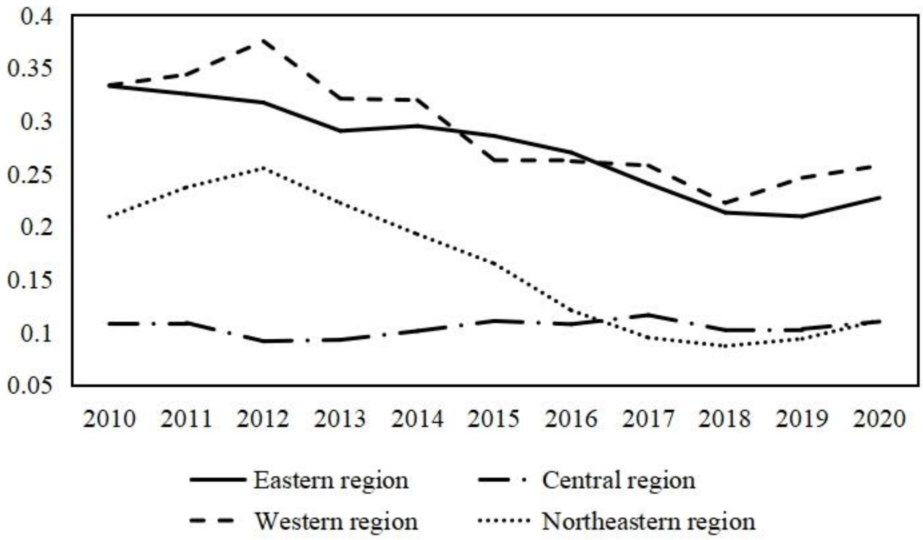

Figure 3. Results of the regional DD index.

4.2.3. Results of Provincial DD

The results calculated using the two generalized entropy index methods are consistent (Table 4). Using the Theil index as an example, the national DD index decreased from 0.4731 in 2010 to 0.2560 in 2020, with a 4.59 percentage point average annual decrease. The DD index in the four major regions also exhibits a declining trend. However, except for a few provinces, such as Jilin, Hainan, and Ningxia, where the DD index exhibits a declining trend over the entire sample period, the index of other provinces is increasing. The two situations above are not contradictory as, on the one hand, the level of digital economy development in cities across the country is constantly improving within the sample interval, particularly in cities with initially low levels of digital economy development, resulting in a narrowing of the overall digital economy development gap among cities. On the other hand, the gap in digital economy development within provinces is widening. For instance, during the process of digital economy development, the digital economy level in Zhengzhou City, Henan Province, and Xi'an City, Shaanxi Province, is gradually significantly higher than that of the other cities, which has significantly increased the DD index within provinces. Overall, the national or regional DD index declines when the narrowing degree of digital economy development disparities across provinces is greater than the increasing degree of internal digital economy development differences in particular provinces. Although the imbalanced development of the national digital economy is decreasing, the significant improvement in the level of digital economy development in particular cities within the province may widen DD, which is still worthy of attention.

Table 4. Changes in provincial DD index between 2010 and 2020.

Province	2010	2020	Average Growth Rate	Province	2010	2020	Average Growth Rate
Nation (Theil)	0.4731	0.2560	−4.59%	Hubei (Theil)	0.1627	0.1700	0.71%
Nation (MLD)	0.5107	0.2951	−4.22%	Hubei (MLD)	0.3548	0.3681	0.37%
Hebei (Theil)	0.0281	0.0525	8.64%	Hunan (Theil)	0.0848	0.1300	5.43%
Hebei (MLD)	0.0274	0.0533	9.42%	Hunan (MLD)	0.0793	0.1159	4.62%
Shanxi (Theil)	0.0535	0.0980	8.31%	Guangdong (Theil)	0.3842	0.3700	−0.41%
Shanxi (MLD)	0.0456	0.1048	12.96%	Guangdong (MLD)	0.3630	0.5066	3.96%
Inner Mongolia (Theil)	0.1257	0.3906	21.08%	Guangxi (Theil)	0.1379	0.3100	12.63%
Inner Mongolia (MLD)	0.4475	0.6521	4.57%	Guangxi (MLD)	0.1251	0.4481	25.81%
Liaoning (Theil)	0.0640	0.1386	11.65%	Hainan (Theil)	0.1427	0.0100	−9.47%
Liaoning (MLD)	0.0630	0.1296	10.56%	Hainan (MLD)	0.1817	0.0077	−9.58%
Jilin (Theil)	0.1112	0.0331	−7.02%	Sichuan (Theil)	0.2209	0.2600	1.58%
Jilin (MLD)	0.0952	0.0320	−6.63%	Sichuan (MLD)	0.4803	0.3923	−1.83%
Heilongjiang (Theil)	0.1713	0.1515	−1.16%	Guizhou (Theil)	0.1939	0.3000	5.28%
Heilongjiang (MLD)	0.1442	0.3512	14.35%	Guizhou (MLD)	0.1709	0.3375	9.75%
Jiangsu (Theil)	0.0960	0.1022	0.65%	Yunnan (Theil)	0.3935	0.4500	1.50%
Jiangsu (MLD)	0.0966	0.0985	0.20%	Yunnan (MLD)	0.9143	0.9646	0.55%
Zhejiang (Theil)	0.0200	0.0435	11.74%	Tibet (Theil)	0.2043	0.4100	9.85%
Zhejiang (MLD)	0.0195	0.0412	11.12%	Tibet (MLD)	0.2107	0.3566	6.93%
Anhui (Theil)	0.0691	0.1357	9.65%	Shaanxi (Theil)	0.0621	0.2200	25.45%
Anhui (MLD)	0.0704	0.1534	11.80%	Shaanxi (MLD)	0.0532	0.4493	74.37%
Fujian (Theil)	0.1110	0.3059	17.56%	Gansu (Theil)	0.2481	0.2500	0.19%
Fujian (MLD)	0.1183	0.2586	11.86%	Gansu (MLD)	0.4692	0.5144	0.96%
Jiangxi (Theil)	0.0457	0.1905	31.72%	Qinghai (Theil)	0.4344	0.8200	8.79%
Jiangxi (MLD)	0.0460	0.1725	27.50%	Qinghai (MLD)	1.1207	1.8014	6.07%
Shandong (Theil)	0.0864	0.1065	2.32%	Ningxia (Theil)	0.3284	0.1600	−5.21%
Shandong (MLD)	0.0960	0.1024	0.66%	Ningxia (MLD)	0.7874	0.1427	−8.19%
Henan (Theil)	0.0628	0.4753	65.69%	Xinjiang (Theil)	0.1672	0.1600	−0.41%
Henan (MLD)	0.0656	0.3720	46.73%	Xinjiang (MLD)	0.1569	0.2286	4.57%

4.2.4. Decomposition of DD at Regional and Provincial Levels

Considering that the performance of the Theil index is similar to that of the MLD index, this study considers the Theil index as an example for analysis. The national DD index is classified in this study to examine the contribution of DD in the four regions (Figure 4). The performance of the MLD index is shown in Figure A2. From an intra-regional and inter-regional perspective, the intra-regional contribution rate is greater than the inter-regional contribution rate. Moreover, the contribution rate within regions is constantly increasing, whereas that among regions is declining, and the gap between the two is widening. This result indicates that DD within the region plays a leading role in the overall changes in DD, and its impact is constantly increasing. Overall, the contribution rate among provinces is higher than that within provinces, but the former is declining, whereas the latter is steadily increasing. This result indicates that DD among provinces plays a leading role in overall changes in DD, but the impact of DD within provinces is constantly increasing. The above findings support the study's hypothesis that intra-regional and inter-provincial contribution rates are important in changes in the national DD. Existing measurement results show that both exhibit a declining trend within the sample interval, demonstrating a general trend of narrowing the national DD. Although the provincial DD continues to increase, its contribution to the overall DD is relatively slight; therefore, it cannot influence the overall trend. However, owing to the increasing contribution rate within the province, the governments should still focus on the development of the digital economy among different cities within the same province. This approach will avoid excessive agglomeration of digital industries in individual cities, increase the degree of imbalance in digital economy development within the province, and cause the "Matthew effect".

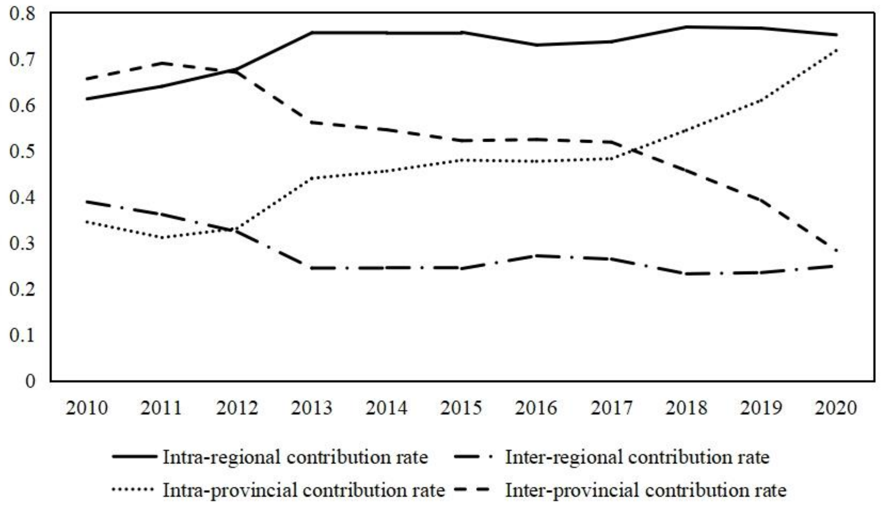

Figure 4. Results of the classification of DD at regional and provincial levels.

5. Determinants of DD

5.1. Regression Results for the Full Sample

This study uses a two-way fixed-effects regression model to examine the determinants of DD in China. Table 5 shows the results, where columns (1)–(3) represent the regression results with the addition of determinants of physical, human, and social capital, respectively. Column (4) represents the comprehensive regression results with the addition of three types of determinants. Notably, in general, the impact of economic growth on income distribution does not necessarily exhibit a linear relationship [65]. Therefore, the square term of economic growth is also included in the regression analysis. Given that the results of the MLD and Theil indices are consistent, this study uses the DD index measured by the Theil index method for regression analysis.

Table 5. Results of the determinants of DD.

Variable	**(1)**	**(2)**	**(3)**	**(4)**
	DD	**DD**	**DD**	**DD**
Economic growth	−0.1064 ** (0.0439)			−0.1758 *** (0.0547)
Square of economic growth	0.0006 *** (0.0002)			0.0008 *** (0.0003)
Industrial structure	0.0098 (0.1415)			−0.0413 (0.1409)
Infrastructure	−0.1677 *** (0.0576)			−0.1809 *** (0.0615)
Foreign trade	0.0159 *** (0.0045)			0.0129 ** (0.0054)
Fiscal revenue	0.5061 (0.3614)			0.4345 (0.3893)
Aging		−0.0051 (0.0044)		−0.0066 (0.0050)
Education		−0.0238 (0.0149)		−0.0300 * (0.0166)
Innovation		−0.0008 (0.0006)		−0.0004 (0.0009)
Online interaction			0.0579 ** (0.0256)	0.0885 *** (0.0340)
Social organization			0.0011 (0.0040)	−0.0031 (0.0046)
Province FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	297	297	297	297
R^2	0.2913	0.2484	0.2486	0.3223

Note: The coefficients with ***, ** and * are significant at the 1%, 5% and 10% confidence levels.

The following conclusions can be drawn from the regression results. (1) The impact of economic growth on DD is significantly negative, whereas the square term of economic growth has a significantly positive impact on DD. This result indicates that a non-linear "U-shaped" relationship exists between economic growth and DD. The possible reason is that after controlling for determinants of physical, human, and social capital in the early stages of digital economy development, as the level of economic development increases, the opportunities of the disadvantaged groups in DD to access and use digital technology also increase, therefore narrowing DD. However, although other determinants, such as digital infrastructure and education, remain constant, further development of digital technology can only benefit those who have better digital infrastructure and high levels of Internet skills, therefore potentially widening DD. (2) The impact of infrastructure on DD is significantly negative. With the improvement of the infrastructure level, the availability of digital technology in underdeveloped areas of the digital economy continues to increase, and the gap in digital economy development among regions is gradually narrowing. (3) The impact of foreign trade on DD is significantly positive. The possible reason is that China's foreign trade development is significantly heterogeneous. The eastern coastal cities have developed rapidly in foreign trade, with a high level of development. Moreover, with the development of digital technology, several new forms of foreign trade have emerged, such as digital product trade and digital service trade. However, the central and western inland regions do not have significant advantages in foreign trade. The trade level gaps may further widen DD through various channels, such as technological innovation and digital trade. (4) The impact of aging on DD is not significant. The possible reason is that a region's level of digital economy development depends mostly on the development of its digital industry and is not strongly correlated with its internal population structure. At the micro level, elderly individuals' digital literacy tends to be inadequate, putting them vulnerably exposed to DD. However, at the macro level, the high proportion of elderly people is not directly related to the level of digital economy development. (5) The impact of education on DD is significantly negative. As the level of education in a region increases, the gap in digital skills among residents decreases. Therefore, the disadvantaged groups are likely to use digital technology to improve their benefits, and the gap in digital economy development among regions is also narrowing. (6) The impact of online interaction on DD is significantly positive. The possible reason is that the development of communication technology is mostly limited within the local area and mainly promotes the growth of the digital economy in the region, with less flow of digital elements among regions. Through online interaction, social capital within regions with advantages in digital technology continues to accumulate, and communication technology is developing rapidly. However, social capital in regions with disadvantages in digital technology has not been significantly improved, so DD may widen. Furthermore, the impact of offline social organizations on DD is not significant, which means that the accumulation of online social capital is the main factor affecting DD. This study also used the DD index measured based on the Gini index for regression to ensure the robustness of the results (Table A1). The results are consistent with those presented in Table 5.

5.2. Regression Results in Different Periods

This study divides the complete sample interval into two periods, 2010–2015 and 2016–2020, and carries out regression analysis separately to evaluate the dynamic changes in the determinants of DD. This study divides the period based on the structure of China's economic growth and the characteristics of digital economy development. The specific reasons are as follows. China's economic growth rate continues to decline. In October 2015, the Chinese government proposed a new development concept of innovation, coordination, green, openness, and sharing. This event indicates that China's economic development has begun to shift from targeting high growth quality and that the driving structure of China's economic development has begun to shift toward high levels. However, in early 2016, the Chinese government officially proposed a national cyber development strategy, which further improved China's digital infrastructure. Moreover, in 2016, digital technologies, such as artificial intelligence, virtual reality, and cloud computing, sparked a wave of development, and a new generation of shared economy, such as shared bicycles, ride-hailing, and homestays, gradually entered and influenced public life. Therefore, this study divides the research period into two sections based on 2015.

According to the results shown in Table 6, the following conclusions are drawn. First, the impact of economic growth on DD is mostly shown in the first period, suggesting that the influence of economic growth on DD becomes insignificant when the economic growth rate declines. Second, the impact of fiscal revenue on DD is significantly positive in the second period, which may be because, in the stage of economic slowdown, fiscal revenue determines investment in the digital economy industry to some extent. Cities with high fiscal revenue have great support for the development of the digital economy, which may widen the digital economy development gap within cities with low fiscal income, therefore increasing DD. Third, the influence of innovation on DD is significantly negative in the second period. This finding shows that with the transformation of the economic development structure, innovation has gradually become an important factor in promoting the development of the digital economy. As the overall level of innovation increases, the speed of digital technology updates also increases, which includes the penetration effect of digital technology on economic development. Disadvantaged provinces can also benefit from an increasing variety of digital economy growth. Fourth, the significant negative impact of education level on DD is only reflected in the previous period. Residents in provinces with low levels of digital economy development can use digital technology to increase their benefits. However, the bridging effect of continuing education level improvement on DD gradually weakens. Finally, the effect of online interaction on DD is significantly positive in both periods. The result shows a high degree of online communication and interaction among residents within cities. However, the information flow has been spreading across provinces to a lesser extent, which is not conducive to the balanced development of the digital economy.

Table 6. Results of the determinants of DD in different periods.

Variable	DD	
	(1) **2010–2015**	**(2)** **2016–2020**
Economic growth	−0.1641 ** (0.0808)	−0.1616 (0.1915)
Square of economic growth	0.0007 * (0.0004)	0.0008 (0.0009)
Industrial structure	−0.3340 (0.2917)	0.0398 (0.2500)
Infrastructure	−0.1377 (0.1445)	−0.1827 (0.1172)
Foreign trade	0.0065 (0.0097)	−0.0022 (0.0196)
Fiscal revenue	−0.2097 (0.5700)	1.8739 * (0.9992)
Aging	0.0085 (0.0088)	−0.0073 (0.0087)
Education	−0.0538 * (0.0302)	−0.0141 (0.0248)
Innovation	0.0000 (0.0014)	−0.0035 * (0.0018)
Online interaction	0.2246 ** (0.1054)	0.1204 ** (0.0500)
Social organization	0.0032 (0.0097)	−0.0060 (0.0100)
Province FE	Yes	Yes
Year FE	Yes	Yes
Observations	162	135
R^2	0.1702	0.5332

Note: The coefficients with ** and * are significant at the 5% and 10% confidence levels.

6. Discussion

The study on the measurement and the determinants of DD is the basis for bridging DD and the key to exerting the inclusive effect of digital technology. China is a major country in the development of the global digital economy, and evident spatial differences exist in digital economy development [5]. This study uses data from city-level in China to investigate the extent, trends, and determinants of DD, including national, regional, and provincial DD. First, this research constructs a new framework with a comprehensive index system and broadens the definition of DD, which has typically been depicted in past studies using a single ICT indicator or a composite ICT index [10,12,34]. However, the current development of digital technology has exceeded the scope of the ICT industry and covered the integration with traditional industries, such as the industrial Internet [66] and e-commerce [67]. Traditional statistical methods may not cover the entire scope of DD. The development of the ICT industry and the deep integration of digital technology with traditional industries can be summarized as the transformation of economic development driven by digital technology or referred to as the development of the digital economy [1,2]. Therefore, this study defines DD based on the concept of uneven development of the digital economy. The assessment of the digital economy is primarily based on the official standards of the *Statistical Classification of the Digital Economy and Its Core Industries (2021)*, released by the National Bureau of Statistics of China in 2021. Based on the idea of "digital product manufacturing → sales → promotion → penetration → integration", the digital economy index is measured from the five dimensions of digital product manufacturing, digital product services, digital technology application, digital-driven elements, and digital efficiency improvement. This approach includes not only the development of the ICT industry but also dimensions such as industrial Internet, e-commerce, and financial technology. Moreover, in the process of measuring, unlike the equal or subjective weighting method, this study uses the entropy weight method to weigh each subindex, which makes the calculation results highly objective and appropriate [63].

Second, this study uses the generalized entropy index method commonly used in the field of income inequality to measure DD. Most studies have depicted the extent of DD by measuring the relative ranking of ICT indices [4,10,12,35,47], whereas others have used spatial econometric methods for measuring DD [11,19,38,39]. However, none of the above methods can directly measure the exact size of DD. Studies have rarely integrated inequality indicators with research on DD. Some studies have mainly employed only the approaches of relative gap, time distance [41], relative rates [20], and Gini index [21] to evaluate the degree of imbalance in ICT development at the national level. Their conclusion can only reflect the degree of the national DD and cannot investigate regional disparities and the contribution rate of differences to the overall DD. This approach does not address the issue of DD in a targeted manner or promote inclusive development. Hence, the Theil and MLD indices in the generalized entropy index are used in this study to measure DD at the national, regional, and provincial levels, and the results can be decomposed further to investigate the contribution rate. This study's results are consistent with the findings of Loo and Wang [5] and Liu et al. [4] that China has a significant DD, with high ICT level regions concentrated in the east, whereas the development of ICT in western provinces is relatively lagging. However, the two studies neither investigated the extent of DD within provinces nor focused on the relative sizes of the inter-regional and intra-regional contribution rates of DD. The results of our study show that the intra-regional contribution rate of China's DD is expanding and that the intra-regional contribution rate is gradually decreasing, which explains the "differentiation" of the trend of China's overall DD and that of DD within most provinces.

Third, this study explores DD's determinants from three perspectives: physical, human, and social capital. Most studies have only investigated from one dimension, such as examining the impact of economic development differences on unequal access to digital technology [4,24,45–47] and examining the impact of education differences on DD [15,49–51]. However, the determinants of DD are comprehensive and not only determined by a single factor [52,62], so this study investigates all types of potential determinants.

The regression results from the two-way fixed-effects model show that an increase in economic growth can alleviate DD to some extent. However, economic growth does not have a linear effect on DD, which is consistent with the findings of related studies [4,46,47]. Moreover, this study further concludes that improving infrastructure and education levels can significantly curb DD, whereas foreign trade and online interaction are not conducive to further bridging DD. Furthermore, the regression results by period show that the influence of each determinant on DD is dynamic. For example, the influence of economic growth and education level on DD is mainly reflected in the first period, whereas that of financial income and innovation capacity on DD is mainly reflected in the second period.

This study also has certain limitations. First, the currently available data related to the digital economy are only at the city level and cannot be further refined to the district, county, and community levels, therefore narrowing the measurement range of the DD. Second, the statistics related to the integration of digital technology and traditional industries are not comprehensive. This study only includes industrial Internet, e-commerce, and digital finance, for which data are available in the evaluation system, but relevant dimensions such as digital agriculture are lacking. Finally, the measurement of the digital economy in this study does not have strong applicability and spatial comparability. The reason for this is that, on the one hand, the administrative division between China and other countries is not the same, and on the other hand, the digital economy development in each country has certain differences. Moreover, the digital economy evaluation system constructed is not necessarily applicable to all countries. In future research, we will further supplement and refine the relevant data for measuring DD and enhance the applicability and comparability of DD measurement. Therefore, with the continuous improvement of statistical work, subsequent research can be further deepened in terms of defining the scope of the DD and refining basic data. The relevant suggestions include: First, expand the scope of the DD and explore the connotation of the DD within the resident sector and the enterprise sector. The factors affecting the digital divide may also vary within more specific sectors. Second, further explore the unique influencing factors of the DD within different sectors and examine its dynamic change characteristics to provide a basis for more targeted implementation of policies to narrow the DD. Third, the level of DD measurement should be refined from the provincial and urban levels to the district, county, and village levels to provide a reference for a more specific display of the DD.

7. Conclusions and Policy Implications

This study constructs a new framework with a five-dimensional comprehensive index system, and the city-level data are used to measure China's DD index from 2010 to 2020 at the national, regional, and provincial levels. This study also investigates the decomposition of DD at both regional and provincial levels, as well as the determinants of DD from the perspectives of physical, human, and social capital. The conclusions indicates the following: (1) China's digital economy has been showing a growth trend but shows significant spatial heterogeneity. The highest level of digital economy development is in the eastern region, whereas the growth rate of digital economy development is the opposite. The growth rate in the central and western regions is faster, and the development gap within the eastern region is gradually narrowing. (2) China's DD is on a downward fluctuating trend. The gradual implementation of national strategies to accelerate the development of the digital economy in pilot cities, along with the emergence of new digital technologies, may lead to a temporary increase in the DD. (3) DD within the eastern and western regions is relatively large, showing a gradual downward trend, whereas DD within the central region is the smallest. However, DD within most provinces is showing an increasing trend. (4) The intra-regional contribution rate of DD is greater than that of the inter-regional, and the intra-regional contribution rate is increasing, whereas the inter-regional contribution rate is decreasing. The intra-provincial contribution rate is smaller than that of the inter-provincial, but the intra-provincial contribution rate is increasing year by year, whereas the inter-provincial contribution rate is decreasing. Intra-regional and inter-provincial contribution rates dominate the movement of the national DD, which is the reason for the declining national DD. (5) The improvement of economic growth will narrow DD in the short term, but the impact of economic growth on DD in the long term presents a non-linear relationship. The improvement of infrastructure and education can significantly curb DD, whereas foreign trade and online interaction are not conducive to further bridging the DD. (6) The impact of various determinants on DD is dynamic, such as the impact of economic growth and education mainly reflected in the first period. The impact of fiscal revenue and innovation on DD is mainly reflected in the second period, and online interaction significantly affects DD in both periods.

This study has the following policy implications. First, the development of the digital economy should be continuously promoted, and the deep integration of the digital economy with traditional industries should be facilitated. In particular, the development of the digital economy in disadvantaged regions should be strengthened to enhance the digital infrastructure of the corresponding regions and to improve residents' digital literacy. Furthermore, this implication applies not only among regions within a country but also between developing and developed countries. Developing countries with relatively underdeveloped digital economies should strengthen infrastructure construction and improve residents' digital skills. Second, the results show that the growth rate of the digital economy in eastern provinces is relatively low. This means that the eastern region still needs to continuously strengthen its digital technology innovation and increase the training of digital talents. It also needs to continuously create new digital economic growth points, play the role of the national digital economy development engine, and drive the development of the digital economy in central and western regions. Third, although government departments are working to narrow the digital economy development gap between provinces and bridge the DD, the focus of policies should be highly in favor of that within provinces and combine the policies at both the regional and national levels effectively. For example, in terms of technical support, talent transfer, equipment sharing, and others, the assistance provided by cities with a higher level of digital economy development within the same province to other cities should be strengthened. Fourth, on the premise of continuously upgrading the level of regional economic development, attention should also be paid to the role of infrastructure, education, and innovation capacity enhancement in bridging the DD. The infrastructure of disadvantaged regions should be continuously improved, the level of education for all needs to be raised, and the overall capacity for innovation must be enhanced. Additionally, strengthening the flow of information among regions and enhancing the spillover effect of digital technology development from high- to low-level cities is crucial. Fifth, statistical departments should continuously strengthen the data basis for measuring DD and enhance the statistical work on digital technology. Statistical departments should continue improving statistical systems and survey methods and further utilizing new digital technologies, such as big data, blockchain, and cloud computing, to collect and organize statistical data. Moreover, data collection channels should be broadened, the types of digital technology-related data collection should be increased, and the accuracy and timeliness of digital technology-related statistics should be improved.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

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Conflicts of Interest: The authors declare no conflicts of interest.

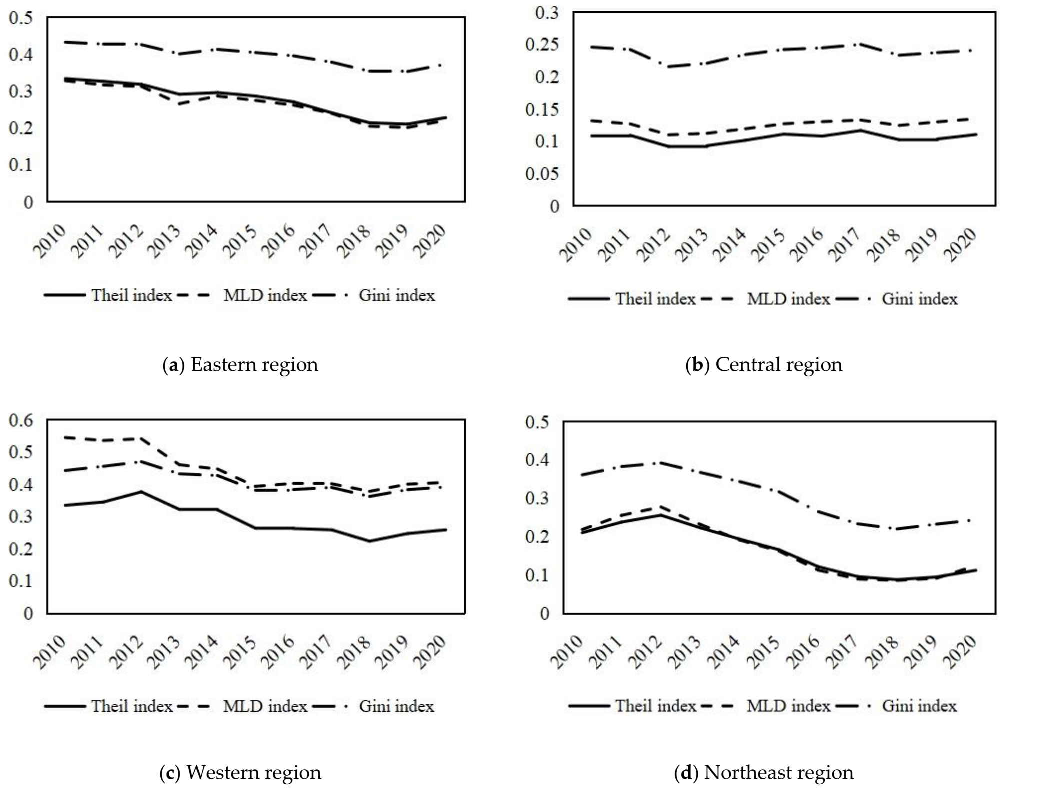
Appendix A

Table A1. Results of the determinants of DD (Gini index).

Variable	(1)	(2)	(3)	(4)
	DD	DD	DD	DD
Economic growth	−0.1297 *** (0.0386)			−0.1596 *** (0.0478)
Square of economic growth	0.0006 *** (0.0002)			0.0008 *** (0.0002)
Industrial structure	−0.0748 (0.1245)			−0.1124 (0.1231)
Infrastructure	−0.1063 ** (0.0507)			−0.1609 *** (0.0537)
Foreign trade	0.0149 *** (0.0040)			0.0135 *** (0.0047)
Fiscal revenue	0.3169 (0.3179)			0.1356 (0.3402)
Aging		0.0006 (0.0039)		−0.0023 (0.0044)
Education		−0.0313 ** (0.0131)		−0.0431 *** (0.0145)
Innovation		−0.0001 (0.0005)		0.0007 (0.0008)
Online interaction			0.0331 (0.0226)	0.0802 *** (0.0297)
Social organization			−0.0008 (0.0035)	−0.0073 * (0.0040)
Province FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	297	297	297	297
R^2	0.2856	0.2470	0.2360	0.3262

Note: The coefficients with ***, ** and * are significant at the 1%, 5% and 10% confidence levels.

Appendix B



(**a**) Eastern region (**b**) Central region

(**c**) Western region (**d**) Northeast region

Figure A1. Regional DD index based on different measures.

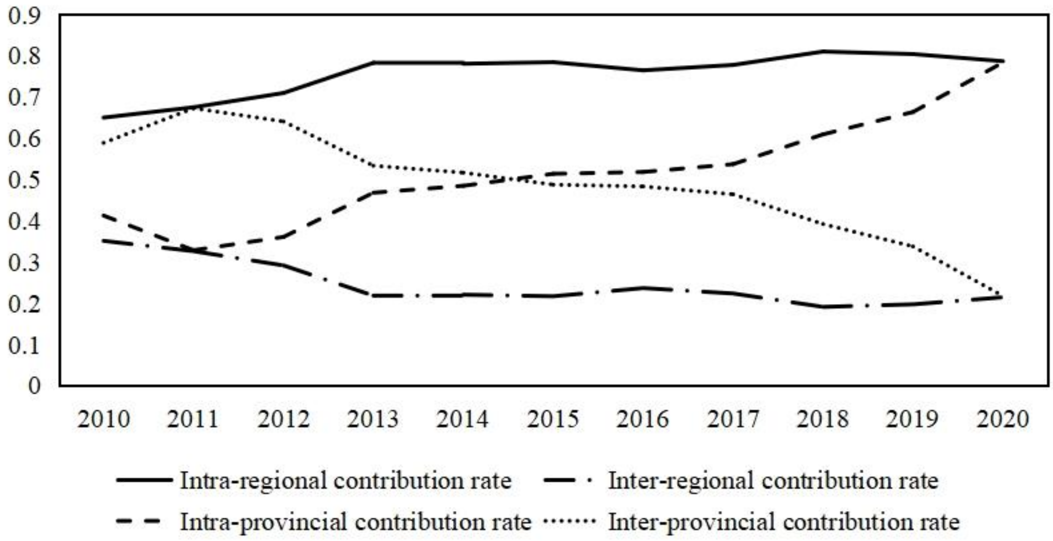


Figure A2. Results of the decomposition of the DD at regional and provincial levels (MLD Index).

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