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Measuring Spatial Differences of Informatization in China

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Abstract: As the wide application of new Information and Communication Technologies (ICTs) shows, the world is moving fast towards an information age. Since China was first connected to the Internet in 1994, the development of ICTs in China and around the world has been astonishingly fast, and yet there is a clear 'digital divide' among different regions in China. Although Chinese geographers have paid attention to regional differences in informatization, they usually employ a limited number of indicators, mainly focusing on the Internet. In fact, informatization is a much broader concept, covering not only the Internet, but also mobile phones as well as user ability. In the light of these considerations, this study provides a comprehensive examination of the development of informatization and its spatial differences in China. First, based on a literature review, the paper identifies 29 preliminary indicators for measuring informatization, and employs principal components analysis and the fuzzy analytic hierarchy process to streamline them into 12 indicators to form an ICTs Development Index (*IDI*). Second, by using the data from provincial statistical yearbooks and the China Internet Network Information Center, the paper calculates the *IDI* of each mega-region and each province in 2000–2010, and measures the changing spatial differences in the development of informatization in China. Lastly, the paper quantifies the relationship between informatization and economic growth. The empirical results show that the *IDI* of the western and central China has been increasing faster than that of the coastal region, indicating that the digital divide in China has been narrowing.

Keywords: informatization; Information and Communication Technologies (ICTs) Development Index (*IDI*); spatial difference; digital divide

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1 Introduction

Since the 1990s, the wide application of new Information and Communication Technologies (ICTs) has driven the world fast into a digital and information age. The term 'informatization' is usually used in this context, referring to the extent of application of ICTs, which is itself seen as a means of accelerating the development of a region or a country, and as an indicator of the degree to which the region or country has moved in the direction of an information society. For geographers, informatization can be understood as the impacts of the wide application of new ICTs on the relationships between time and space (Graham and Marvin, 1996). Recognized as one of the most profound dimensions of technological progress in the last few decades, new ICTs have been reducing the time and space barriers to information transmission, making access to information faster and easier, and changing the traditional geographical law relating to friction of distance (Liu *et al.*, 2004; Song and Liu, 2013). These changes have generated geographical attention, challenging the popular

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view that distance no longer matters and that 'the end of geography' is near at hand. These debates have generated a large volume of geographical literature focusing on the spatial impacts of new ICTs on social and economic spatial organization (Graham and Marvin, 2001; Sohn *et al.*, 2002; Zhen and Gu, 2002; Liu *et al.*, 2004; Wang and Ning, 2004; Wilbanks, 2004; Nunzia, 2005; Lu *et al.*, 2008; Dunning, 2009; Shen *et al.*, 2010; Song and Liu, 2013). In these studies, it is argued that distance still plays a role although new ICTs have transformed the spatial organization of social and economic activities by changing business models and consumption patterns, reducing transaction costs and space-time barriers, and facilitating the rapid and geographically-extensive diffusion of innovation and knowledge (Wilbanks, 2004; Dunning, 2009; Song *et al.*, 2009). And yet, there are huge digital divides worldwide because the societal diffusion and spatial distribution of ICTs are spatially uneven at all scales.

Since the very beginning of these debates, geographers have paid attention to spatial differences in the development of new ICTs at various scales (Abramson, 2000; Moss and Townsend, 2000; Townsend, 2001; Wolcott *et al*., 2001; Liu, 2002; Liu and Zhang, 2003; Lu and Liu, 2005; Ning *et al*., 2010; Wang and Qiu, 2011). However, the existing literature focuses on the spatial distribution of the Internet (i.e. Internet penetration, Internet users and IP addresses), and little has been done on the comprehensive measurement of informatization and its spatial differences. Indeed, informatization is a broader concept, covering not only the Internet but also the use of mobile phones and other IT equipment as well as user ability. These considerations call for a broader concept and measure of informatization.

It is noteworthy that, in the last decade, China has been on the fast track of informatization. According to the China Internet Network Information Center (CNNIC) and International Telecommunication Union (ITU), Internet users in China amounted to 5.64×10^8 in 2012. Among these users, 4.2×10^8 accessed the Internet via mobile cellular networks, accounting for 74.5% of all users. Internet penetration in China reached 42.1% in 2012, 3.8% higher than that in 2011. However, spatial differences in informatization have not yet been given sufficient attention by policy makers and scholars. Both the 11th Five-Year Plan and 12th Five-Year Plan of China called for a comprehensive measure of informatization to capture spatial variation in the development of an information society in China.

In this study, we shall attempt to examine comprehensively the development of informatization in China and its spatial differences. First, we shall identify 29 preliminary indicators for measuring informatization based on a literature review, and then employ principal components analysis and a fuzzy analytic hierarchy process to streamline them into 12 indicators to form an ICT development index (*IDI*). Second, we shall compute national, regional and provincial *IDI* of China in 2000–2010, and measure the digital divide and the development towards an information society in China. Lastly, we will try to monitor the social and economic impacts of ICTs development by examining the relationship between growth and the rise of an information society.

2 Literature Review

To date, numerous studies have sought to measure informatization and its spatial differences. Early research mainly focused on the Internet and its spatial distribution, especially the overall ability of individuals to access and use the Internet. Moss and Townsend (2000), for example, analyzed the development of the Internet in America and its spatial characteristics. In their studies, the development of the Internet is measured by the growth and geographical dispersion in the number of Internet users, Internet access price, and time-on-line. When Liu and Zhang (2003) measured the development of the Internet in China, they considered the number of Internet users, the number of domain names registered under 'CN', and the information resource and business use of Internet. Abramson (2000) built the Internet Globalization Indicators, which included computer penetration, fixed telephone penetration, mobile phone penetration, the number of Internet users, Internet bandwidth, websites and language.

Since 2003, studies dealing with the measurement of informatization have been extended to examine the digital divide. These studies are more comprehensive than the early researches, but little has been done in respect of environmental factors, consumption factors and knowledge. The digital access index proposed by the ITU (2003) considers such factors as infrastructure, affordability, knowledge (adult literacy, and school enrollment), quality (bandwidth per capita and broadband subscribers) and usage. Chen and Wellman (2003) suggested that indicators of access and use should be weighed by socio-economic status, gender, life stage and geographic location. Bridges.org (2003) proposed the following indicators: the number of users or computers, infrastructure access, affordability, training, relevant content, IT sector (size of ICTs sector and integration into existing industries), and certain demographic characteristics (geography, race, age, religion, gender and disability). Lenhart (2003) measured Internet access and the digital divide in America in terms of the communication channels and capacity, number of computers, fixed telephone line penetration, mobile cellular penetration, websites, Internet use frequency, time-on-line, governmental support and social funding.

Kim (2004) proposed to measure informatization using a composite measurement, which has attracted increasing attention from scholars. A comprehensive study of the relevant literature reveals several additional promising aspects to be considered in appraising informatization. For example, National Bureau of Statistics of China (2005) built the ICTs development index (IDI_{CN}), which suggested the inclusion of the environmental and consumption factors. The environmental factor comprised the development environment of informatization, composed of IT sector output, R&D investment in the IT sector and regional per capita GDP. The consumption factor referred to an ICTs consumption index. ITU (2006) built the ICTs development index (IDI_{ITU}), proposing two new indicators: the number of fixed broadband subscribers and the number of mobile broadband subscribers. The OECD (2008) also built the OECD Key ICTs Indicators (IDI_{OECD}), and suggested some new factors, such as social and governmental constraints/support.

Table 1 summarizes the indicators for measuring informatization, as proposed by existing studies. Most studies focus on the development of ICTs, and therefore usually emphasize temporal factors rather than spatial factors. As a result, the current indicators are limited, especially in terms of quantifying the spatial characteristics and spatial implications of informatization (Taylor and Zhang, 2007). Although ITU has concentrated on international differences, the ITU index is not as clearly applied at more local levels of analysis. It is our argument that the digital divide is both an international issue and a domestic issue at the local, provincial and mega-regional levels. Therefore, an attempt to construct a multivariate ICTs index may produce evidence heretofore concealed.

3 Data Sources and Methodology

3.1 Constructing a composite indicator

3.1.1 Selection of indicators

Constructing a composite measure of informatization poses several methodological and substantive challenges (Martin, 2003), and should begin with a serious examination of the indicators used in measurement (Hoffman *et al*., 2000). The first step was to identify the most relevant indexes and sets of indicators concerning the development of ICTs. Table 1 lists 29 indicators found in the existing literature, and identifies them as I_1–I_{29}. From this list we very carefully chose indicators that met the following criteria (ITU, 2003; Lenhart., 2003; Kim, 2004; CNNIC, 2005; OECD, 2008; ITU, 2009):

(1) an indicator must be relevant to an issue according to the definition of informatization;

(2) an indicator must be measurable;

(3) indicators have to be independent from each other and must have no mutual overlap;

(4) data for the indicators must be available from scientific or institutional public sources;

(5) data must be available for all provinces, or at least for all but the smallest provinces;

(6) data must be recent and be regularly updated.

First, we deleted four indicators on the grounds that they are outdated or unsuitable, namely I_1 (television penetration), I_{25} (ethnic diversity), I_{26} (racial diversity), and I_{27} (language). Second, we checked the relationship between indicators, and deleted four overlapping indicators. For example, both I_7 (physical layer (infrastructure price)) and I_8 (logical layer (software price)) could be represented by I_6 (Internet access price); in most studies, I_{17} (users' skills) could be measured by I_{16} (adult literacy rate); I_5 (number of ISPs per capita) was very similar to I_{20} (websites per capita). Third, data availability and quality for each province in China were checked, given that the index should cover as many provinces as possible. Since ICT data availability in many provinces is poor, this factor also restricted the selection of indicators, leading to the deletion of I_{10} (frequency), I_{11} (time-on-line), and I_{29} (investments in and funding of ICTs) and leaving only 18 of the original set. Fourth, principal components analysis (PCA) was carried out to

Table 1 Summary of current indicators for measuring ICTs development

Category	Indicator	Reference
Infrastructure	Television penetration	DiMaggio and Hargittai, 2001; Norris, 2001; Horrigan and Rainie, 2004
	Proportion of households with computer	Hoffman *et al*., 2000; DiMaggio and Hargittai, 2001; Norris, 2001; Liu and Zhang, 2003; OECD, 2008; ITU, 2009; CNNIC, 2012
	Fixed telephone penetration	Hoffman *et al*., 2000; Norris, 2001; Chen and Wellman, 2003; ITU, 2003; OECD, 2008; ITU, 2009; CNNIC, 2012
	Mobile celluar penetration	Bridges.org, 2003; ITU, 2003; OECD, 2008; ITU, 2009; CNNIC, 2012
	Number of Internet service providers (ISPs) per capita	DiMaggio and Hargittai, 2001; Warschauer, 2002; Horrigan and Rainie, 2004
Affordability	Internet access price	Norris, 2001; Cooper, 2002; Bridges.org, 2003; ITU, 2003; Lenhart, 2003; Martin, 2003; ITU, 2003; OECD, 2008
	Physical layer (infrastructure price)	Norris, 2001; Cooper, 2002; Lenhart, 2003; Horrigan and Rainie, 2004
	Logical layer (software price)	Norris, 2001; Cooper, 2002; Lenhart, 2003; Horrigan and Rainie, 2004
Use	Internet users per 100 inhabitants	Norris, 2001; Cooper, 2002; Liu, 2002; Warschauer, 2002; Chen and Wellman, 2003; Lenhart, 2003; Liu and Zhang, 2003; Martin, 2003; ITU, 2003; Liu, 2006; OECD, 2008; ITU, 2009; Wand and Qiu, 2011;CNNIC, 2012
	Frequency	DiMaggio and Hargittai, 2001; Hargittai, 2002; Warschauer, 2002; Chen and Wellman, 2003; Crump and Mcllroy, 2003; Lenhart., 2003
	Time-on-line	Hargittai, 2002; Warschauer, 2002; Chen and Wellman, 2003; Crump and Mcllroy, 2003; Lenhart, 2003
Quality	Fixed broadband subscribers per 100 inhabitants	Martin, 2003; Taylor and Zhang, 2007; ITU, 2009
	Mobile broadband subscribers per 100 inhabitants	Martin, 2003; Taylor and Zhang, 2007; ITU, 2009
	Internet bandwidth per Internet user	ITU, 2003; Liu and Zhang, 2003; Liu, 2006; ITU, 2009; CNNIC, 2012
	Annual growth rate of Internet resource	Liu and Zhang, 2003; Kim, 2004; Liu, 2006; CNNIC, 2012
Knowledge	Adult literacy rate	Hoffman *et al*., 2000; Bridges.org, 2003; Donnermeyer, 2003; Martin, 2003; Lenhart, 2003; Bell *et al*., 2004; ITU, 2009
	Users′ skills	Donnermeyer, 2003; Kim, 2004; CNNIC, 2012
	Primary school enrolment ratio	ITU, 2003; Kim, 2004; OECD, 2008
	Secondary school enrolment ratio	ITU, 2003; Kim, 2004; OECD, 2008; ITU, 2009
	Tertiary school enrolment ratio	ITU, 2003; Kim, 2004; OECD, 2008; ITU, 2009
Accessibility	Websites per capita	Hoffman *et al*., 2000; Norris, 2001; Liu, 2002; Bridges.org, 2003; Chen and Wellman, 2003; CNNIC, 2012
	Domain names per capita	Liu, 2002; Liu, 2006; CNNIC, 2012
Social factors	Gender	Hoffman *et al*., 2000; Bridges.org, 2003; Donnermeyer, 2003; Martin, 2003; Lenhart., 2003; Bell *et al*., 2004; OECD, 2008; CNNIC, 2012
	Age	Hoffman *et al*., 2000; Bridges.org, 2003; Donnermeyer, 2003; Martin, 2003; Lenhart., 2003; Bell *et al*., 2004; CNNIC, 2012
	Ethnic diversity	Hoffman *et al*., 2000; Donnermeyer, 2003; Martin, 2003; Lenhart, 2003; Bell *et al*., 2004; CNNIC, 2012
	Racial diversity	Hoffman *et al*., 2000; Donnermeyer, 2003; Martin, 2003; Lenhart, 2003; Bell *et al*., 2004
	Language	Donnermeyer, 2003; Lenhart, 2003; Bell *et al*., 2004; OECD, 2008
Economic factors	ICTs industry output value	Chen and Wellman, 2003; Martin, 2003; Taylor and Zhang, 2007; OECD, 2008
	Investments in and funding of ICTs	DiMaggio and Hargittai, 2000; Warschauer, 2002; Chen and Wellman, 2003; Crump and Mcllroy, 2003; OECD, 2008

analyze the underlying nature of the remaining data, to explore whether the different dimensions are statistically well-balanced, and to reveal how different indicators are associated with and change in relation to each other. Table 2 shows the correlation matrix of the indicators. Some indicators have strong relationships with each other, with correlation coefficient exceeding 0.8 (r_{ij}> 0.8). Six highly correlated indicators were deleted, namely I_6 (Internet access price), I_{15} (annual growth rate of Internet user), I_{18} (primary school enrolment ratio), I_{22} (domain names per capita), I_{23} (gender), and I_{24} (age). The 12 remaining indicators were used to form the ICT Development Index (*IDI*) (Table 3).

3.1.2 Statistical derivation of ICT Development Index weights

In choosing the weights to attach to each indicator in constructing the index, the results of the PCA were first taken into consideration. The PCA assigns a preliminary

Table 2 Correlation matrix of indicators

	I_2	I_3	I_4	I_6	I_9	I_{12}	I_{13}	I_{14}	I_{15}	I_{16}	I_{18}	I_{19}	I_{20}	I_{21}	I_{22}	I_{23}	I_{24}	I_{28}
I_2	1	–0.420**	0.678**	–0.200	0.070	0.360**	–0.264*	0.383**	0.354**	0.470**	0.816**	0.545**	0.548**	0.050	–0.385**	0.798**	–0.239*	–0.100
I_3		1	0.791**	0.820**	0.598**	0.248*	–0.345**	0.403**	0.382**	0.374**	0.160	0.446**	0.608**	–0.020	–0.332**	0.781**	–0.120	–0.040
I_4			1	–0.208*	0.615**	0.170	0.539**	–0.070	–0.120	–0.060	–0.080	0.190	0.534**	–0.080	–0.354**	0.380**	–0.130	0.225*
I_6				1	–0.309**	–0.080	–0.213*	–0.425**	0.903**	–0.261*	–0.428**	–0.150	–0.384**	0.000	–0.241*	0.902**	–0.180	0.160
I_9					1	0.080	–0.258*	0.540**	0.524**	0.445**	0.200	0.476**	0.555**	–0.100	–0.296**	–0.190	0.808**	–0.100
I_{12}						1	0.259*	0.070	0.050	0.413**	0.263*	0.333**	0.381**	0.366**	0.070	0.368**	–0.110	–0.130
I_{13}							1	0.516**	0.493**	0.544**	0.180	0.663**	0.552**	0.050	–0.313**	0.895**	–0.239*	–0.110
I_{14}								1	0.935**	–0.170	0.631**	0.378**	0.405**	0.100	–0.040	0.615**	–0.080	–0.275**
I_{15}									1	0.755**	0.910**	0.360**	0.332**	0.070	0.010	0.594**	–0.140	–0.275**
I_{16}										1	0.602**	0.492**	0.409**	0.426**	–0.040	0.661**	–0.190	–0.231*
I_{18}											1	0.150	0.591**	0.262*	0.180	0.266**	0.903**	–0.253*
I_{19}												1	0.500**	0.180	–0.160	0.761**	–0.297**	–0.130
I_{20}													1	0.150	0.804**	0.520**	–0.392**	–0.274**
I_{21}														1	0.090	0.160	–0.090	–0.090
I_{22}															1	–0.247*	0.350**	–0.130
I_{23}																1	–0.290**	–0.160
I_{24}																	1	0.170
I_{28}																		1

Note: **, * present significant level at the 0.01 and 0.05, respectively

Table 3 Conceptual framework of ICTs Development Index (*IDI*)

Index	Sub-index	Indicator
ICTs Development Index (*IDI*)	ICTs infrastructure indicators	Fixed telephone penetration
		Mobile cellular penetration
		Proportion of households with computer
		Internet bandwidth per Internet user
	ICTs use indicators	Internet users per 100 inhabitants
		Fixed broadband subscribers per 100 inhabitants
		Mobile broadband subscribers per 100 inhabitants
		Annual growth rate of Internet resource
	ICTs support indicators	Adult literacy rate
		Secondary school enrolment ratio
		Tertiary school enrolment ratio
		ICTs industry output value

Notes: Internet resource means the number of websites and number of webpages; ICTs industry means manufacture of communications equipment, computers and other electronic equipments

relative weight to each indicator. Second, a fuzzy analytic hierarchy process (FAHP) was carried out to revise statistically and derive a finalized weight for each indicator. The FAHP, first developed by Saaty and Vargas (2000), is a popular tool used to solve hierarchically complicated multi-level decision problems. It involves several steps:

(1) Organizing a weighting problem hierarchically. In this step, the weighting problem is structured as a family tree (Table 3).

(2) Developing judgment matrices by pairwise comparisons (Equation (1)). The judgment matrices are made up of pairwise comparisions of indicators at the same level, or sub-indices.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{1}$$

The resulting judgment matrix identifies the importance of each indicator. More specifically, r_{mn} is the relative priority of indicator m and n, and m and n are the number of indicators.

$$r_{mn} = f(w_m - w_n) \tag{2}$$

where w_m is the weight of indicator m; and w_n is the weight of indicator n.

S_i is also a judgment matrix identifying in this case the importance of sub-index i, and is defined as

$$\begin{array}{c|cccc} S_i & I_1 & I_2 & \cdots & I_m \\ \hline I_1 & r_{11} & r_{12} & \cdots & r_{1m} \\ I_2 & r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ I_n & r_{n1} & r_{n2} & \cdots & r_{nm} \end{array} \tag{3}$$

where I_m is the indicator m; r_{nm} is the priorities indicator for indicator n relative to indicator m; m and n are the number of indicators included in the sub-index i.

(3) Calculating the weights of indicators from the judgment matrices. A consistency check should be implemented for each judgment matrix. The weights were defined as

$$r_{ij} = 0.5 \pm a(w_i - w_j) \qquad i, j = 1, 2, \ldots n \tag{4}$$

where r_{ij} is the priorities indicator for indicator i relative to indicator j; w_i is the weight of indicator i; and w_j is the weight of indicator j.

(4) Ranking the weights. The final step is to compute a weighted sum of the relevant indicators to obtain the weights of the sub-index (Table 4).

3.2 Computing *IDI* and regional variations in informatization

(1) Normalization of data. As the indicators are measured in different units, the first step is to transform the values into the same measurement units by normalizing them.

(2) The *IDI* is calculated by computing:

Table 4 ICTs Development Index and weights of indicators

Index	Sub-index	Weight	Indicator	Weight
ICTs Development Index (*IDI*)	ICTs infrastructure indicators	0.379	Fixed telephone penetration	0.064
			Mobile cellular penetration	0.098
			Proportion of households with computer	0.102
			Internet bandwidth per Internet user	0.115
	ICTs use indicators	0.376	Internet users per 100 inhabitants	0.124
			Fixed broadband subscribers per 100 inhabitants	0.076
			Mobile broadband subscribers per 100 inhabitants	0.102
			Annual growth rate of Internet resource	0.074
	ICTs support indicators	0.245	Adult literacy rate	0.049
			Secondary gross enrolment ratio	0.069
			Tertiary gross enrolment ratio	0.062
			ICTs industry output value	0.065

$$IDI = \sum_{i=1}^{n} Y_i (\sum_{j=1}^{m} Y_{ij} X_{ij}) \tag{5}$$

where IDI is the value of IDI for each province in China; X_{ij} is the value of indicator j in sub-index i; Y_{ij} is the weight of indicator j in sub-index i; Y_i is the weight of sub-index i; n is the number of sub-indices; and m is the number of indicators.

(3) Measuring regional variation and the size of the digital divide. The coefficient of variation (CV) is computed as the digital divide is a 'relative concept' (Liu and Zhang, 2003; ITU, 2009). The CV can be expressed as:

$$CV = \frac{S}{IDI_a} = \frac{1}{IDI_a}\sqrt{\frac{\sum_{i=1}^{n}\left(IDI_i - IDI_a\right)^2}{n-1}} \tag{6}$$

where IDI_i is the IDI value of province i; IDI_a is the average value of 31 provinces in China; S is the standard deviation; and n is the number of provinces. From a statistical point of view, the data values are more dispersed if the value of CV is larger. In other words, the digital divide in China is widening if the value of CV is increasing, and the digital divide in China is narrowing if the value of CV is getting smaller.

3.3 Data sources

It should be pointed out that our data only cover 31 provinces in China, not including Chinese Macau, Hong Kong and Taiwan for the lack of statistical data. Northeast China includes Liaoning, Jilin and Heilongjiang. The eastern China includes Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong and Hainan. The central China includes Shanxi, Henan, Anhui, Jiangxi, Hunan and Hubei. The western China includes Inner Mongolia, Guangxi, Shaanxi, Ningxia, Gansu, Qinghai, Xinjiang, Tibet, Yunnan, Guizhou, Chongqing and Sichuan (Fig. 1).

The underlying data relating to fixed telephone penetration, mobile phone penetration, Internet users per 100 inhabitants, adult literacy rate, primary school enrolment ratio, secondary gross enrolment ratio, tertiary gross enrolment ratio, gender, age and ICTs industry output value were collected from *China Statistical Yearbook* (NBSC, 2001–2011) and *Provincial Statistical Yearbook* (NBSC, 2001–2011); the data relating to fixed broadband subscribers per 100 inhabitants, mobile broadband subscribers per 100 inhabitants, proportion of households with computer and annual growth rate of Internet resource were taken from the *China Information Almanac* (State Information Center, 2001–2011); and the data on domain names, websites, Internet bandwidth per Internet user and Internet access price came from the *Statistical Report on Internet Development in China* (CNNIC, 1997–2013).

4 Growth and Spatial Differentiation of Informatization in China

Eleven years (i.e. from 2000 to 2010) is a relatively long period in terms of information society development. By their nature, ICTs are very dynamic, and infrastructure and access values may change considerably as a result of changes in the market environment, enhanced in-

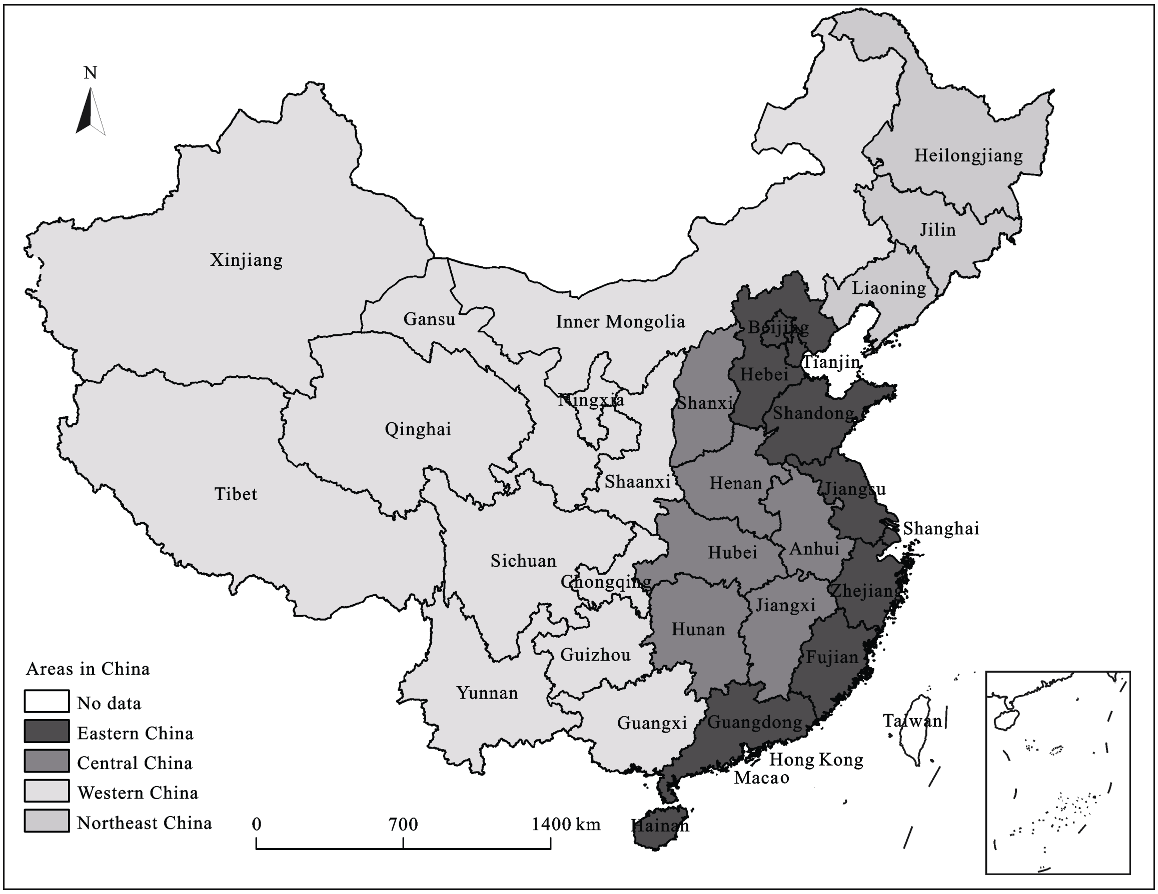


Fig. 1 Division of four mega-regions in China

vestments, price cuts, policies, or new technologies (ITU, 2011). Therefore we analyzed the spatial features of informatization in China based on the data for 2010, and measured the changing spatial differences in the development of informatization based on the data for 2000–2010.

4.1 Overview of informatization in China

China is a latecomer in the field of informatization, starting almost ten years later than developed countries. Before the 1990s, there were only several experimental Internet communication facilities between Chinese scholars and their collaborative foreign partners (Liu, 2002). The 1990s witnessed a boom in the development of informatization in China, as evidenced by an incredible increase and popularization of computers, access to Internet and ICTs services. Since 2000, the development of informatization in China has accelerated remarkably. For example, the *IDI* value of China increased from 0.478 to 0.697 in 2000–2010, with a 3.84% annual growth rate (Fig. 2). Tracking the progress of China's drive towards an information society, we divide it into three stages: preliminary development; network building; and in-depth integration.

Preliminary development (2000–2003). In China, the so-called 'informatization tide' came in quite late (Liu, 2002). Starting from 2000, China entered an early stage of information society development, and ICTs infrastructure construction was taken as the central issue for national modernization. During this stage, China concen-

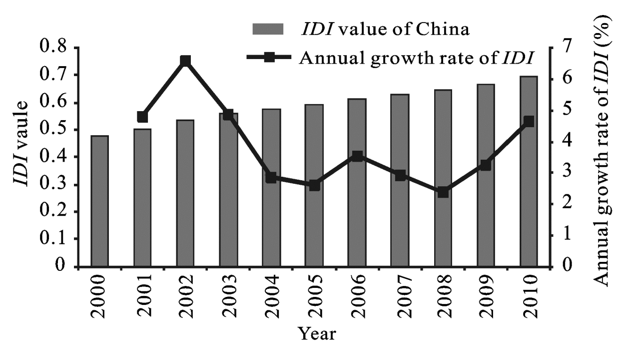


Fig. 2 Development of ICT Development Index (*IDI*) in China, 2000–2010

trated on building the basic ICTs framework, forming a unified Internet network, and achieved a fast development of informatization, with a 5.41% annual growth rate of *IDI*. For example, Internet users in China increased from 2.20 × 10^7 to 8.00 × 10^7 in 2000–2003. In 2003, China had 2.70 × 10^8 mobile phone users, 2.63 × 10^8 fixed telephone users and 7.95 × 10^7 Internet users, with the Internet penetration rate at 6.2% (Fig. 3). At the same time, the majority of counties in China were connected to the Internet, with the exception of 68 counties in the central and western China.

Network building (2004–2008). The second stage of informatization development was characterized by the extension of the existing ICTs infrastructure and the formation of an interconnected national network. In 2004, the Chinese central government implemented the strategy of 'integration of informatization and industrialization'. ICTs networks expanded comparatively fast, and informatization development took significant strides forward, with a 2.89% annual growth rate of *IDI*. In 2004–2008, the total domain names registered under 'CN' rose from 3.8 × 10^5 to 1.2 × 10^6, IPV4 addresses tripled from 4.94 × 10^7 to 1.58 × 10^8, and Internet penetration grew sharply from 7.23% to 22.6% (Fig. 3). As of July 2008, the number of Internet users in China totaled 2.53 × 10^8, ranking first in the world for the first time and surpassing the 2.23 × 10^8 users of the United States. At the end of 2008, China had 6.41 × 10^8 mobile phone users, 3.40 × 10^8 fixed telephone users, and 2.98 × 10^8 Internet users.

In-depth integration (since 2009). After 2009, China has attached great emphasis to strengthening the 'integration of informatization and industrialization' and expanding the rural Internet network. In coping with the global economic crisis, the Chinese government adopted a series of policies and measures to stimulate domestic demand and boost investment, greatly facilitating domestic development of ICTs. For example, the Chinese government stressed investments in infrastructure, and over 12% of the infrastructure investment (1.7 × 10^{11} yuan (RMB)) was earmarked for ICTs infrastructure construction. Priority was given to rural ICTs infrastructure projects in various parts of China, leading to an acceleration of network upgrading in vast rural areas. In addition, the central government launched the consumer electronics subsidy program and the ten-year IT industrial revitalization plans. As a result, China still managed to achieve a 3.95% annual growth rate of *IDI* in 2009–2010 in the wake of the global financial crisis. In 2010, China had more than 8.59 × 10^8 cell phone users, 2.94 × 10^8 fixed telephone users and 4.57 × 10^8 Internet users, and Internet penetration was 34.3% (Fig. 3).

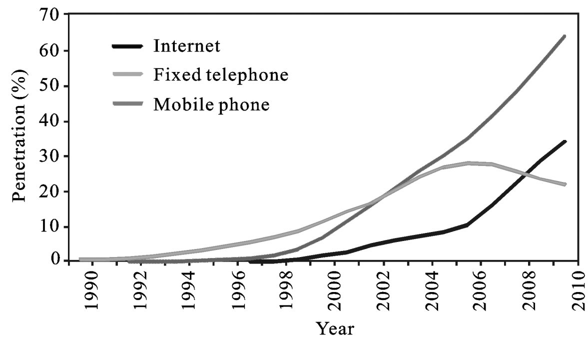


Fig. 3 General pattern of informatization development in China, 1990–2010

4.2 Spatial features of informatization in China

4.2.1 Provincial differences of informatization

A marked provincial digital divide exists in China. For example, Beijing topped the *IDI* in 2010 with an *IDI* = 0.931, which is 1.66 times greater than that of Tibet, the province with the lowest *IDI* at 0.562. Only nine advanced provinces in terms of ICTs have higher *IDI* values than the national average; the other 22 provinces are under-developed in terms of informatization. In order to track the progress made by different provinces over time and compare the magnitude of the differences among them, we used hierarchical cluster analysis to group the provinces (Table 5). SPSS was used to identify relatively homogeneous groups of provinces, based on both the between-groups linkage cluster method and the within-groups linkage cluster method.

Topmost (*IDI* values above 0.873). This group only includes 2 municipalities, Beijing and Shanghai, with

Table 5 Grouping of provinces with different informatization levels

Group	Number of provinces	Share in population (%)	*IDI* (2010)	
			Minimum	Maximum
Topmost	2	3.20	0.873	0.931
High	7	27.63	0.713	0.784
Upper	7	25.63	0.653	0.691
Medium	11	36.83	0.624	0.647
Low	4	6.71	0.562	0.613
All provinces	31	100.00	0.562	0.931

the highest levels of informatization. Both are located in the eastern China. Together the 2 municipalities accounted for 3.2% of China′s population and 6.09% of its Internet users in 2010 (Fig. 4).

High (*IDI* values between 0.713 and 0.784). The seven provinces included in this group have a high level of informatization. These provinces accounted for 27.63% of China′s population in 2010. Figure 4 shows that, except for Liaoning from Northeast China and Shaanxi from the western China, the other five provinces are all located in the eastern China.

Upper (*IDI* values between 0.653 and 0.691). The 7 provinces in this category, noted for their fast-growing informatization, come from different mega-regions (Fig. 4), such as Shandong and Hebei from the eastern China, Shanxi and Hubei in the central China, Jilin from Northeast China, and Chongqing and Inner Mongolia in the western China. Their total population reaches almost 3.42×10^8.

Medium (*IDI* values between 0.624 and 0.647). The 11 provinces in this group accounted for more than one-third of China′s total population (36.83%). Figure 4 shows that these provinces come from the four mega-regions, such as Hainan from the eastern China, Heilongjiang from Northeast China, Hunan, Jiangxi, Anhui and Henan provinces from the central China, and Ningxia, Xinjiang, Sichuan, Guangxi and Gansu provinces from the western China.

Low (*IDI* values below 0.613). The remaining 6.71% of China′s inhabitants can be found in this group, featured by a low level of informatization. The four provinces, namely Qinghai, Guizhou, Yunnan and Tibet, are all located in the western China.

4.2.2 Regional differences of informatization

There are remarkable spatial differences in informatization among the four mega-regions in China. There is a gradual decline in the level of informatization from east to west, which is highly consistent with the spatial pattern of economic growth in China. Table 6 shows that the eastern China is the most developed mega-region in terms of informatization, with an *IDI* = 0.758 in 2010, much higher than the national average. The central and western mega-regions are both under-developed in terms of informatization, with their *IDI* values respectively at 0.648 and 0.632. And Northeast China has the medium level of informatization with *IDI* = 0.673.

4.3 Spatio-temporal evolution of informatization in China

4.3.1 Changes at provincial scale

There are significant changes in the spatial pattern of provincial informatization in 2000–2010 (Fig. 5). First, although all provinces have made remarkable progress in moving towards an information society, Tibet, Jiang-

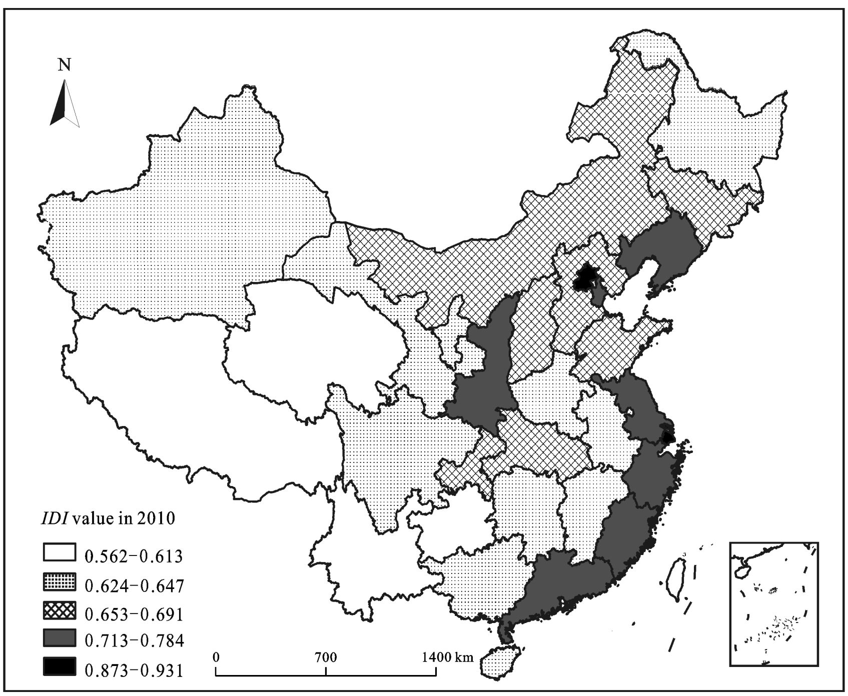


Fig. 4 Spatial differences of ICTs Development Index (*IDI*) in China, 2010

Table 6 ICTs Development Index (*IDI*) of four mega-regions, 2010

Mega-region	*IDI* value	Internet penetration	Mobile phone penetration	Fixed telephone penetration
Eastern China	0.758	0.438	0.796	0.282
Central China	0.648	0.271	0.502	0.173
Western China	0.632	0.276	0.565	0.169
Northeast China	0.673	0.358	0.659	0.259
National	0.697	0.343	0.644	0.221

su, Guizhou, Zhejiang, Shanxi and Shaanxi have achieved the most improvements in *IDI* values, respectively at 0.279, 0.254, 0.247, 0.245, 0.244 and 0.233 points. The fastest improving provinces are Tibet, Guizhou, Shanxi, Yunnan, Shaanxi and Jiangsu, whose *IDI* values improved by 1.97, 1.68, 1.54, 1.52, 1.51 and 1.51 times. Among them, Tibet, Guizhou, Yunnan and Shaanxi are located in the western China, and Shanxi in the central China. In other words, the *IDI* values of provinces in the western and central China have been increasing faster than those of the coastal region. Second, provincial *IDI* ranking has changed notably in 2000–2010. Overall, ten provinces moved upwards in the *IDI* ranking, twelve provinces moved downwards, and nine provinces remained unchanged. It is noteworthy that Shanxi in the central China increased its rank most, rising sharply to the 11th place in 2010. Heilongjiang and Xinjiang saw their ranks decline the most. Indeed, while some provinces in the western and central China moved up in *IDI* ranking, some coastal provinces, especially in Northeast China, moved down. Third, the calculation results reveal that provincial $CV = 0.116$ in 2010 had decreased from $CV = 0.167$ in 2000. In addition, the provincial *IDI* gap between Beijing and Tibet narrowed from 0.433 in 2000 to 0.369 in 2010. These changes indicate that the digital divide at the provincial level has narrowed significantly over the eleven-year period, although it continues to exist.

4.3.2 Changes at mega-regional level

In general, the four mega-regions have achieved remarkable improvements in the degree of informatization in 2000–2010 (Table 7). The western China was the fastest-growing area, with a 4.15% annual growth rate of *IDI*. Next to it was the central China, whose *IDI* value

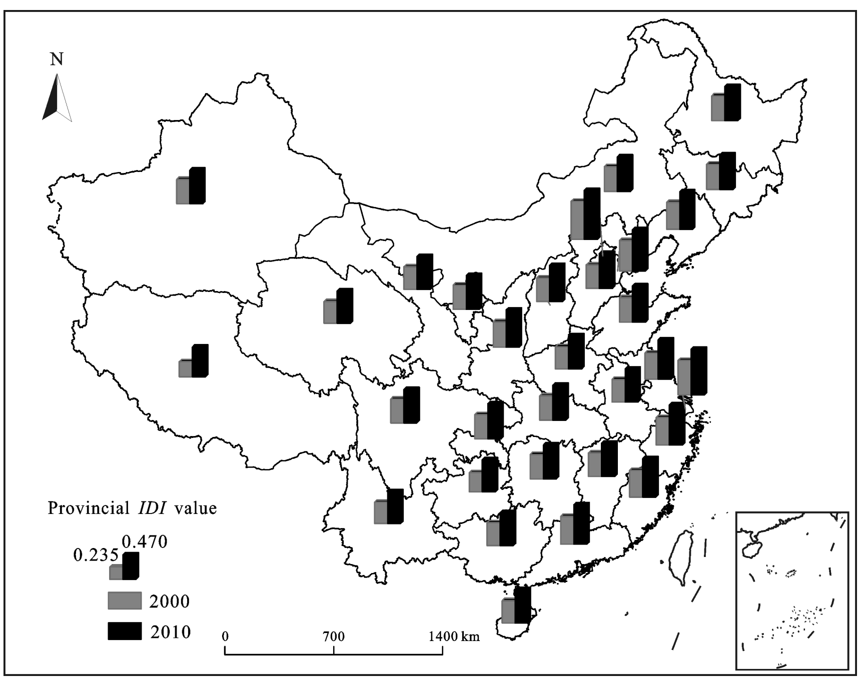


Fig. 5 Changing spatial differences of ICTs Development Index (*IDI*) in China, 2000–2010

Table 7 ICTs Development Index (*IDI*) changes in four mega-regions, 2000–2010

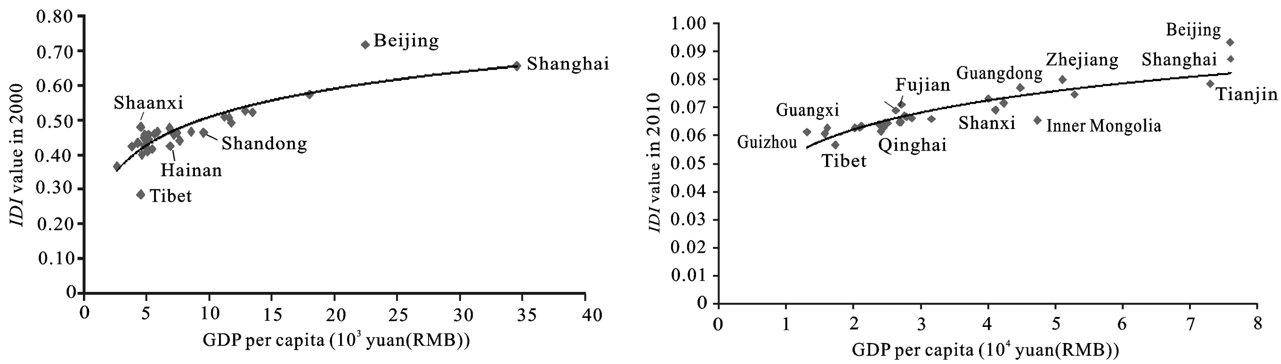
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Eastern China	0.531	0.558	0.591	0.622	0.639	0.664	0.689	0.707	0.717	0.734	0.758
Central China	0.440	0.461	0.491	0.519	0.531	0.551	0.575	0.588	0.597	0.618	0.648
Western China	0.421	0.442	0.473	0.501	0.515	0.528	0.553	0.572	0.585	0.607	0.632
Northeast China	0.483	0.505	0.549	0.569	0.583	0.596	0.611	0.629	0.634	0.649	0.674
CV	0.104	0.105	0.103	0.098	0.099	0.102	0.098	0.097	0.094	0.088	0.083

increased from 0.440 in 2000 to 0.648 in 2010, with a 3.95% annual growth rate. The eastern China was much lower than the central and western China, with a 3.62% annual growth rate. Northeast China gained the least in terms of *IDI* value points (0.191), with a 3.39% annual growth rate. These changes bear testimony to the fact that the digital divide at the mega-regional level is getting narrower albeit slowly. Table 7 shows that the mega-regional *CV* values fluctuated slightly in 2000–2005, and decreased year by year since 2006. As a result, the spatial pattern of informatization at the mega-regional level did not change much over the eleven years. The eastern China always topped the *IDI*, Northeast China ranked the 2nd, while the western China came last.

4.4 Economic implications of informatization

One of the key policy concerns with regard to information society measurement is to examine the drivers of ICTs development and to monitor its social and economic impacts (Kitchin, 1998; Castells, 2010). In this context, the relationship between informatization (*IDI*) and economic development measured by per capita GDP is aroused concerns. ICTs sectors are relatively small in relation to the overall size of the economy: although ICTs development is an important driver of growth, its direct contribution to aggregate GDP is generally small. ICTs technologies are however generic technologies that are taken up throughout the economy with particular concentrations in some of the more advanced sectors. In these circumstances it is reasonable to assume that there is a causal relationship between GDP and informatization. Initial plots of this relationship for the period 2000–2010 indicated however that the relationship is non-linear, so that in this study the relationship was modeled by using a logarithmic regression of informatization on per capita GDP (Fig. 6). This model provides a good fit for the 2000–2010 data, with a coefficient determination of 0.7594; in other words, the regression explained nearly 76% of the variance.

Separate regressions were estimated for each year. Over time the statistical explanatory power of the relationship increased: the coefficient of determination (R^2) of the logarithmic regression of *IDI* on GDP increased from 0.7326 in 2000 to 0.8140 in 2010, while the slope of the curve increased indicating that the impact of GDP on informatization increased. These changes indicate that, more recently, economic growth had a stronger impact on ICTs development than in earlier years. This finding helps confirm the earlier finding reported in Part 4.2 that spatial distribution of informatization was highly consistent with the spatial pattern of economic



(a) 2000 (b) 2010

Fig. 6 Relationship between ICTs Development Index (*IDI*) and gross domestic product (GDP) in China. We mainly pointed out the outliers with confidence interval equal to 0.05

growth in China. It also suggests that the ICTs content of economic growth is increasing.

A closer look at the logarithmic regression of *IDI* on GDP reveals that there are a number of outliers with some provinces lying above or below the fitted line in Fig. 6. These provinces all have higher/lower-than-expected ICTs levels given their provincial economic development levels. In 2010, among those that have higher than expected informatization levels are several of the top ranking *IDI* provinces: Beijing, Shanghai, Guangdong, Fujian, Zhejiang and Shaanxi. Guangxi and Guizhou, with relatively low economic development levels, have much higher-than -expected informatization levels. Provinces with lower-than-expected informatization levels include resource exporting provinces, such as Inner Mongolia, Shanxi, Tibet and Qinghai. These provinces clearly have followed a different economic growth strategy, focusing on their rich natural resource endowments. Given the level of development of their provincial economies, there is still great potential for further ICT-led development.

5 Conclusions

Measuring spatial differences of informatization is indispensable for a better understanding of how far China has moved towards an information society in the 21st century, and is significant in supporting nation-wide informatization planning and decision-making. Based on the existing literature, this study built an *IDI* model to examine spatial differences in informatization in China, and identified the relationship between ICTs development and economic growth.

First, this study indicates that there are significant spatial differences of informatization in China, and that these differences are highly consistent with its spatial pattern of economic growth. Most provinces in the eastern China rank highly on the *IDI* index in 2010, while provinces in the western China generally occupied low positions in the rank order. Second, the spatio-temporal analysis shows that the spatial pattern of informatization has changed dramatically in 2000–2010. Tibet, Guizhou, Shaanxi, Yunnan, and Shanxi provinces in the western and central China have experienced significant and speedy improvements in the *IDI*, evidencing that the digital divide in China has been shrinking. Last, but not least, this study reveals that there is a strong correlation between *IDI* and per capita GDP. A logarithmic regression model shows that, given their respective economic growth levels, most provinces in the eastern China have much higher-than-expected *IDI* levels while most resource-exporting provinces in the central and western China have much lower-than-expected *IDI* levels.

Following the development of ICTs, the speedy progress of informatization in China will continue to accelerate, and the informatization level in different regions/ provinces will see comprehensive improvement. As it does new issues will demand geographical attention, such as the impact of the digital divide on the economic divide, the impacts of the digital divide on regional spatial patterns, and the factors influencing informatization development. This study aims to provide a general background and a stepping stone for future studies of these issues.

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