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<https://doi.org/10.1057/s41599-023-02390-7>

OPEN

Impact of digital city competitiveness on total factor productivity in the commercial circulation industry: evidence from China's emerging first-tier cities

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In the age of rapid technological advancement, the proliferation of digital technologies has reshaped urban landscapes, affecting economic, social, and environmental dynamics. Urban digital transformation is more than just a technological innovation; it stands at the core of future urban competitive strategies. As this trend evolves, the commercial circulation industry is poised for significant opportunities. However, the academic exploration into the relationship between the level of urban digitalization and the total factor productivity of the commercial circulation industry remains limited. To address this gap, this study employs data from 15 emerging first-tier cities in China. Initially, a Digital City Competitiveness Index was established, with results indicating Hangzhou taking the lead, while other cities were categorized into distinct tiers. Utilizing a two-way fixed-effects model, the research then investigates the impact of digital city competitiveness on the total factor productivity of the commercial circulation industry. The findings suggest that digital city competitiveness significantly enhances the total factor productivity within this industry. Furthermore, the study examines the influences of various sub-dimensions of digital city competitiveness on total factor productivity. Notably, investments in urban information infrastructure emerge as the most pronounced positive factor, followed by industrial development, innovation, services, and governance. In contrast, the urban ecosystem dimension exerts a negative impact. This research fills an existing void in the literature concerning the relationship between digital city competitiveness and total factor productivity, offering profound insights into the interplay between digital city development and its economic benefits. In addition, the conclusions provide policy implications for decision-makers, highlighting the importance of bolstering urban information infrastructure, encouraging enterprises to innovate, fostering industrial clusters, enhancing urban service capabilities through digital means, elevating public participation, and emphasizing environmental conservation.

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Introduction

Digitalization has breathed new life into urban development worldwide. In this new phase of global economic growth, the digital transformation of cities is not just a technological innovation but is pivotal to constructing the core strategy for future urban competitiveness (Li and Wang, 2020). In China, digital transformation has garnered widespread attention and has ascended to a strategic priority at the national level. Since 2017, the concept of the “digital economy” has been formally incorporated into the Chinese Government’s annual work report (Li and Tian, 2023). Moreover, China has made significant strides in this regard, actively participating in and promoting the construction of digital cities, especially in industries related to the digital economy. According to statistics, by 2021, China’s digital economy reached an astonishing scale of 45 trillion yuan. Moreover, rapid growth trends have been observed in core sectors of the digital economy. For instance, software business revenue skyrocketed from 2.5 trillion yuan in 2012 to 9.6 trillion yuan in 2021¹. The big data industry also surpassed a scale of 1 trillion yuan. Furthermore, China has emerged as the fastest-growing cloud computing market globally, laying a robust foundation for the accelerated advancement of its urban digital transformation. This transformation extends beyond technology; it signifies a shift in thought processes and management. It beckons us to redefine city operations, management, and service models.

The commercial circulation industry serves as integral components of urban economies, playing an irreplaceable role in fostering high-quality urban economic development (Zhao et al., 2020). With the deepening of urban digitalization, the commercial circulation industry is presented with unprecedented development opportunities. Digitalization has not only enhanced efficiency but also enabled the commercial circulation industry to interact with consumers on a broader scale and at a deeper level (Huang et al., 2022). According to the “Global Report on Digital Commerce Development 2021”, technologies like big data, artificial intelligence, and the Internet of Things (IoT) are revolutionizing the operational models and business structures of the commercial circulation industry. Data from Table 1 illustrate that between 2017 and 2021, commercial circulation industry, including wholesale and retail, accommodation and catering, and express delivery, have experienced rapid growth. Notably, in wholesale and retail and express delivery volumes, despite the challenges posed by the COVID-19 pandemic, there has not been a significant setback. This resilience underscores the transformative power and new growth avenues digitalization offers to these sectors. In essence, the nexus between digitalization and commerce is not just a technological union but a harmonious integration of mindset and management strategy. This integration promises higher efficiency, enhanced customer experience, and expansive growth prospects for the commercial circulation industry.

Existing studies have extensively examined the impact of digitalization factors on the commercial circulation industry. However, most have mainly focused on the influence on specific aspects of commerce, such as customer experience (Venables, 2001; Xie and Wang, 2020) or supply chain management

(Ding et al., 2021; Meng et al., 2022; Xie, 2015). In recent years, although the concept of “digital city competitiveness” has emerged and gradually gained attention, in-depth research on its impact on the total factor productivity of the commercial circulation industry remains scarce (Chen et al., 2023). This paper aims to fill this research gap. As the digital economy of cities rapidly advances, the influence of digital capabilities on urban competitiveness becomes increasingly pronounced (Ding et al., 2021). Therefore, what is the level of urban digitization under technological empowerment (digital city competitiveness)? How does it affect the total factor productivity of the commercial circulation industry? And what is the specific mechanism behind these effects? Understanding these questions is undoubtedly crucial for promoting the high-quality development of China’s commercial circulation industry.

Among China’s urban clusters, compared to the traditional four first-tier cities (Beijing, Shanghai, Shenzhen, Guangzhou), the emerging first-tier cities are hubs of population growth² with large consumer market sizes and strong economic vitality, poised to be the primary growth drivers of China’s future economy. Notably, the Chinese government has, in recent years, introduced various policies to encourage the development of these emerging cities, such as new urbanization and the development of city clusters in the central and western regions. Such policy support has accelerated the growth of these cities in economic, technological, and cultural aspects. Hence, this paper, taking 15 of China’s emerging first-tier cities³ as samples, adopts the entropy method to construct a Digital City Competitiveness Index system from six dimensions. It then empirically investigates the impact of digital city competitiveness, both as a whole and in segmented dimensions, on the total factor productivity of the commercial circulation industry in these cities. Potential contributions of this research include: First, by employing the entropy method, this study constructs an index of digital competitiveness for Chinese cities, providing a replicable and adjustable model for subsequent research to measure the digital development level of cities more accurately. Second, this research not only delves into the impact of digital city competitiveness on the overall productivity of the urban commercial circulation industry but also investigates the influence of segmented dimensions of digital city competitiveness on the commercial circulation sector. The comprehensive and segmented approach to this research is pioneering in the field. Lastly, this study offers nuanced insights into both the comprehensive and specific impacts and puts forward targeted policy recommendations. This guidance assists policymakers in more efficiently directing and adjusting urban development strategies, aiming for superior high-quality development in the commercial circulation industry.

The remainder of this paper is structured as follows: “Literature review and comments” presents a literature review and comments; “Digital city competitiveness indicator measurements” discusses the measurement of the Digital City Competitiveness Index; “Empirical model and variable” establishes the empirical model and explains the variables; “Empirical analysis” delves into the empirical analysis; and the final section concludes the whole research.

Table 1 Development of the sub-sectors in China’s commercial circulation industry in 2017–2021.

Business distribution industry segments	2017	2018	2019	2020	2021
Wholesale and retail trade (unit: billion yuan)	630,181.3	691,162.1	782,518.3	864,261.21	877,424.5
Accommodation and catering industry (unit: billion yuan)	9276.71	9682.6	10,900.99	9367.01	10,273
Express delivery business volume (unit: billion pieces)	400.6	507.1	635.2	833.6	1083

Data source: National Bureau of Statistics of China.

Literature review and comments

The digital transformation of the commercial circulation industry has become a significant topic for high-quality development in the context of digitization. Relevant studies have also been extensively discussed from perspectives such as research on the digital economy, the development of the commercial circulation industry, and the impact of the digital economy on promoting the development of the commercial circulation industry.

Research on the digital economy. Digitalization, often heralded as the Fourth Industrial Revolution, catalyzes efficiency enhancements across the entire value chain through the leverage of digital technologies (Wen et al., 2022). This topic has also become a focal point in academic research, with scholars examining it from macro to micro levels. Firstly, at the macro level, researchers have constructed evaluative system indicators from various dimensions such as the internet, digital inclusive finance (Zhao et al., 2020), digital industrialization, and industrial digitization (Yang and Jiang, 2021). For instance, Xu and Zhang (2020) utilized indicators like the industry-added value structure coefficient, digital economy adjustment coefficient, and industry-added value rate to systematically measure the added value and total output of China's digital economy from 2007 to 2017. Wang et al. (2021) further developed a provincial-level digital economy development-level evaluation index system encompassing four dimensions: digital economy development carrier, digital industrialization, industrial digitization, and the environment for digital economy development. (Chen, 2022a) using original data from 276 cities in China from 2011 to 2019, discovered that the digital economy can drive the development of clean energy and urban sustainability performance (Chen, 2023). From an intermediate perspective, whether viewed from an industry or city lens, the positive impact of digitalization on green total factor productivity has been confirmed (Liu et al., 2023; Wang, 2023; Zhu et al., 2022). Shifting to the microlevel, some research has employed text analysis and expert scoring methods to calculate the digital transformation index of enterprises, aiming to precisely gauge the progress of firms in the digital transformation process (Zhao et al., 2021). When discussing the economic effects generated by the digital economy, the perspectives of research become even more diverse. Chen and Kim (2023) found that digital transformation can promote corporate innovation. Positive impacts of digitization on enterprises also manifest in its ability to promote corporate sustainability (Zhang et al., 2022), improve environmental performance (Chen and Hao, 2022), and reduce carbon emission intensity (Chen, 2022b). Moreover, Tian and Li (2022) delved deep into how digital technology influences the transformation of the real economy. They revealed that the close integration of digital technology with the production sector plays a pivotal role in optimizing industry structure and digitizing the real economy. In addition, Tang et al. (2022), by constructing an endogenous growth model that includes data elements, illustrated how the digital economy impacts market structure and innovation performance. In summary, these studies offer a comprehensive perspective, showcasing the entire trajectory of the digital economy from measurement to its economic effects, emphasizing the logical links and complementarity among different research.

Research on the development of the commercial circulation industry. In studies concerning the development of the commercial circulation industry, scholars have predominantly centered their attention on gauging the sector's developmental level and its determinants. First, in terms of assessing the developmental level of the commercial circulation industry, a multitude

of scholars have devised evaluative indicator frameworks. For instance, Chen et al. (2022) chose pertinent metrics spanning four dimensions: scale, structure, efficiency, and facilities, to evaluate the developmental level of the circulation industry across various Chinese provinces. They further delved into the ramifications of the circulation industry's growth on the deepening specialization of China's value chain. Huang and Wen (2019) approached the measurement from three facets: scale, efficiency, and competitiveness, with the aim of discerning the tangible influence of the circulation industry's growth on economic expansion. Ren (2020) utilized an array of metrics, including capital, the marketization degree of labor elements, and circulation efficiency, to gauge the high-quality developmental trajectory of the sector. Concurrently, Chen et al. (2022) undertook a measurement of the high-quality growth of China's commercial circulation industry from 2008 to 2019, encompassing aspects like innovative growth, coordinated evolution, and sustainable development. Moreover, certain scholars opted for singular metrics, such as total factor productivity (Li, 2022) and sectoral added value (Bao et al., 2022), to appraise the growth trajectory of the commercial circulation industry (Sun and Zhang, 2022). When it comes to the determinants influencing the growth of the commercial circulation industry, digital technology (Li, 2022) and the upgrading of the industrial structure (Bao et al., 2022) are perceived as pivotal elements bolstering the sector's high-quality growth. Simultaneously, elements like governmental subsidies (Wan, 2022) and social capital (Peng et al., 2017) have also been validated to exert a pronounced influence on the evolution of the commercial circulation industry.

Research on the impact of the digital economy on the development of the commercial circulation industry. In theoretical aspects, Venables (2001) suggests that the Internet assists businesses in reducing production costs, organizational management expenses, and costs associated with matching and communicating with upstream and downstream suppliers or consumers, as well as logistics transportation costs. Ding et al. (2021) argue that the collaborative application of the Internet of Things, big data, cloud computing, artificial intelligence, and advanced management can lead to information sharing, rapid response, and resource integration in intelligent logistics, especially in goods transportation, warehousing, and distribution. Xie and Wang (2020), including Liu et al. (2019), have examined the impact of the digital economy on the commercial circulation industry from a digital retail perspective. They believe that digital retail, underpinned by next-generation information technology, aims for circulation efficiency, can adapt to changes in supply-demand dynamics, and alleviate the growth challenges of traditional commerce and trade, without altering the essence of circulation and retail. Zhou and Guo (2022) emphasize that digital circulation, anchored by digital platforms, propels the shift from intermittent production based on individual enterprises to continuous production based on the industrial internet. This not only accelerates the realization of commodity value but also reduces circulation costs. Xie (2015) highlights that reverse integration of the supply chain is a novel approach for circulation organizations to counter the de-intermediation impact of the internet era and promote industrial reorganization. Yu and Chen (2020) have observed that the commercial circulation industry's functions are expanding towards production organization, consumer guidance, and value enhancement, with intelligent transformation becoming a focal point for high-quality development in China's commercial circulation industry.

In terms of Empirical Findings, Meng et al. (2022) have shown how the intelligent transformation of the circulation industry can

promote regional economic coordinated development and societal sustainable growth by reducing transportation costs, enhancing total factor productivity, and increasing rural residents' income. Concurrently, Loske and Klumpp (2022), utilizing the Data Envelopment Analysis and Malmquist Index methods, have delved deeply into the impact of digitization on truck drivers' work efficiency, suggesting that in the long run, digital transformation may confer enduring competitive advantages to businesses. Yu et al. (2022) constructed a mathematical model to explore the relationship between the Internet and inter-regional trade costs, discovering that strengthening Internet connections leads to a reduction in inter-regional trade costs. Li (2022) analyzed from a business perspective how digital technology drives the high-quality development of commerce and trade enterprises. Li and Wang (2020) have deeply dissected the digital transformation of the commercial circulation industry, pinpointing core challenges in the transformation process and emphasizing the significance of policy refinement and innovative intelligent business models. Yang and Song (2020) approach the issue from a fresh perspective, the business environment, suggesting that technological and cultural environments positively drive the commercial circulation industry, but local financial environments might pose constraints. To address these challenges, they advocate for bolstering technological innovation. Jiang and He (2022) further corroborate the positive impact of the digital economy on the efficiency of the commercial circulation industry, especially in the realms of new retail and logistics digitization. H. Yang and Cao (2022) offer a novel viewpoint, finding that digital technology investment not only propels the digital transformation of the commercial circulation industry but also significantly boosts its profit margin. Mao et al. (2022) approach from a more macro perspective, exploring how the digital industry enhances the resilience of urban economies. Lastly, Wang (2022) alerts that due to urban resource disparities, the empowering effects of the digital economy vary across cities of different tiers, necessitating consideration of regional differences when formulating policies.

Research gap and hypothesis. Drawing from the existing research, it's evident that various factors, including digitization, and their impact on the commercial circulation industry have been extensively discussed, yielding significant findings. However, the majority of studies on the digital transformation of the commercial circulation industry primarily focus on how digitization affects specific aspects of the industry, such as customer experience, supply chain management, or overall industry growth. Although some research has introduced the concept of "digital city competitiveness" and begun to evaluate and compare digital city competitiveness. However, comprehensive academic evaluations of digital city competitiveness, especially its impact on the total factor productivity of the commercial circulation industry, remain scarce.

Theoretically, digital city competitiveness should have a positive impact on total factor productivity. Specifically, according to the Solow-Swan Growth Model (Swan, 1956), technological progress is one of the key factors in improving total factor productivity. In the context of digital cities, technological innovation will drive the commercial circulation industry to improve its production efficiency and productivity. Moreover, the network effect theory (Katz and Shapiro, 1985) suggests that the value of a system is directly proportional to the number of users of that system. Therefore, in digital cities, as more and more users (including businesses, consumers, and governments) use digital services and platforms, it will help the commercial circulation industry to operate more efficiently. Furthermore, the knowledge

spillover theory (Griliches, 1991) emphasizes that the knowledge and skills of a company or individual may have a "spillover" effect on other companies or individuals. In the environment of digital cities, highly skilled workers and high-tech companies may drive the development of the commercial circulation industry, thereby increasing total factor productivity. Therefore, based on the above analysis, this article proposes the following research hypothesis:

H: Digital city competitiveness will have a promoting effect on the total factor productivity of the commercial circulation industry.

In fact, the continuous upgrade of urban digital economies not only enhances city competitiveness but also manifests in the elevation of cities' digital capabilities. Therefore, there's an urgent need to accurately assess digital city competitiveness and then clarify its precise impact on the efficiency enhancement of the commercial circulation industry. This will provide policymakers with robust references, enabling them to adopt more precise strategies and further propel China's commercial circulation industry toward high-quality development.

Digital city competitiveness indicator measurements

Digital city competitiveness is a new concept, aiming at empowering social governance and public services through digital technology, enhancing the efficiency of city construction, and improving city operation form, so as to promote the upgrading of city concept and efficiency change. While China boasts extensive experience and practical insights in the construction and development of digital cities, there remains a lack of a relatively unified metric system for measuring digital city competitiveness. Drawing from the approach of the CCID Research Institute⁴, this paper establishes a metric system that spans six dimensions: urban information infrastructure construction, urban governance capability, urban service capability, urban industrial development, urban innovation capability, and urban ecological environment.

According to the above index system, the entropy value method is used to determine the weight of each dimensional subdivision index, and the Digital City Competitiveness Index of the sample cities is measured. In view of the comparability of the study, 15 samples of emerging first-tier cities are selected for measurement in this paper (excluding four first-tier cities of Beijing, Shanghai, Guangzhou, and Shenzhen), and the measurement results are obtained as shown in Table 2 and Fig. 1.

From the measurement results in Table 2 and Fig. 1, it can be observed that while there are relatively clear differences in digital city competitiveness levels among China's emerging first-tier cities, there is a very evident average growth trend for all cities from 2017 to 2021. Overall, Hangzhou has the highest Digital City Competitiveness Index, with over 90 points, and is in a distant lead. This is followed by Chongqing, Tianjin, Chengdu, Qingdao, Ningbo, Nanjing, and Wuhan, whose Digital City Competitiveness Indexes all exceed 85 points and are in the second tier, while Suzhou, Xi'an, Dongguan, Changsha, Foshan, Zhengzhou, and Hefei have relatively lower Digital City Competitiveness Indexes.

Empirical model and variable

Empirical modeling. Based on the study by Chen (2022), to elucidate the impact of digital city competitiveness on the total factor productivity of the commercial circulation industry, an empirical model was established as shown in Eq. (1):

$$Tfp_{it} = \beta_0 + \beta_1 DC_{it} + \beta_2 Controls_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (1)$$

In Eq. (1), Tfp_{it} represents the total factor productivity variable of the commercial circulation industry for city i in year t . DC_{it} denotes the digital competitiveness variable for city i in year t .

Table 2 Results of Digital City Competitiveness Index of emerging first-tier cities in China.

City	2017	2018	2019	2020	2021	Average
Chongqing	86.33	88.73	90.32	91.34	93.24	89.992 (2)
Hangzhou	89.43	93.24	94.33	95.24	97.94	94.036 (1)
Chengdu	85.43	86.32	88.32	90.32	92.13	88.504 (4)
Qingdao	83.42	85.34	87.45	89.43	90.21	87.17 (5)
Tianjin	85.32	86.43	88.43	90.43	92.12	88.546 (3)
Suzhou	81.42	83.42	85.54	86.56	87.34	84.856 (9)
Wuhan	83.24	84.53	86.44	88.95	89.23	86.478 (8)
Xi'an	78.43	80.12	82.32	84.32	85.33	82.104 (10)
Nanjing	83.24	85.43	86.55	88.12	89.32	86.532 (7)
Zhengzhou	74.32	76.4	77.84	79.43	80.32	77.662 (14)
Dongguan	75.64	79.43	80.12	82.34	84.32	80.37 (11)
Ningbo	84.34	85.64	86.94	88.42	90.43	87.154 (6)
Changsha	76.42	78.43	79.56	81.38	82.17	79.592 (12)
Hefei	73.21	74.64	75.66	78.54	79.53	76.316 (15)
Foshan	74.34	75.43	78.43	80.23	82.14	78.114 (13)

Note: The figures in Table 2 are the ranking of digital city competitiveness indices of different cities according to their average values.

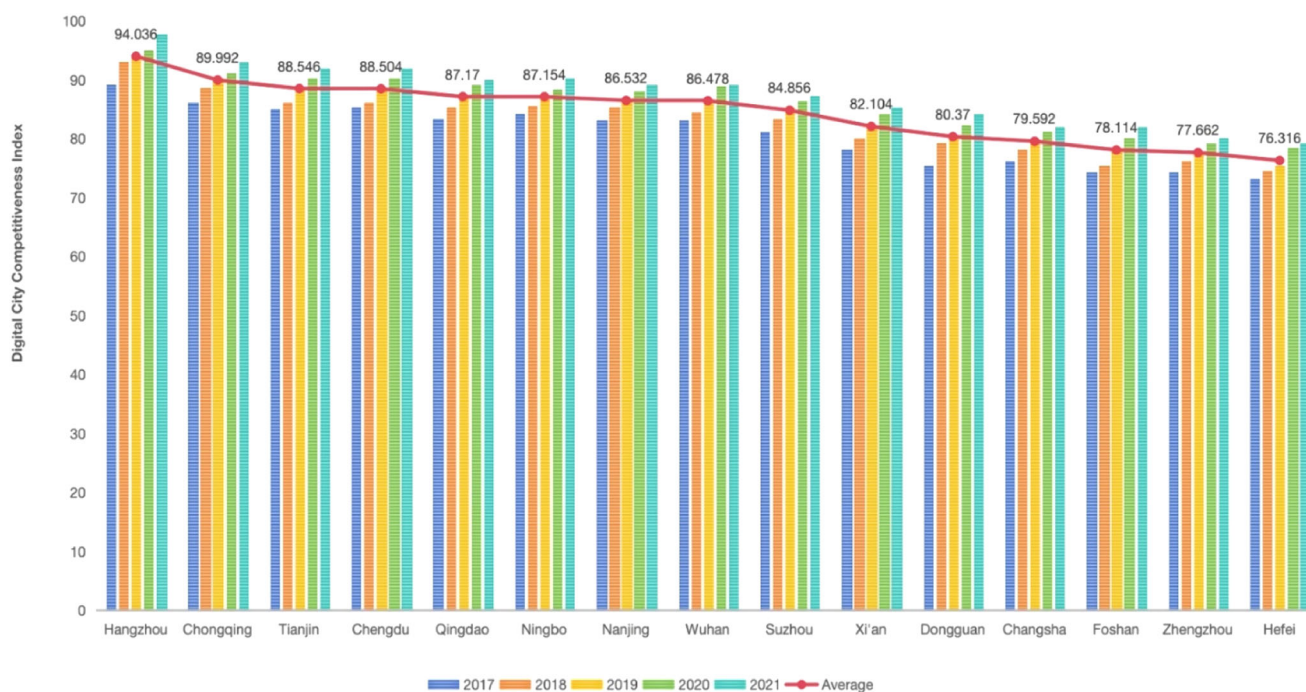


Fig. 1 Digital City Competitiveness of 15 emerging first-tier cities from 2017 to 2021. This figure illustrates the Digital City Competitiveness Index for 15 emerging first-tier cities, plotted on the vertical axis. The horizontal axis represents names of cities. Different colors in the graph indicate the Digital Competitiveness Index level for each city in the respective year. The red dots signify the average Digital City Competitiveness Index for each city.

$Controls_{it}$ refers to a series of control variables. μ_i represents the dummy variable for regional fixed effects, while η_t stands for the dummy variable for time fixed effects. The significance and direction of β_1 are crucial to the study.

Description of data on relevant variables.

- a. Dependent variable: total factor productivity variable of the commercial circulation industry (Tfp). Based on the research by Loske and Klumpp (2022), The Malmquist Index based on input-output analysis is used to measure the data of wholesale and retail trade, transportation (including express logistics), and accommodation and catering industry in three major cities, and the specific

formula is in Eq. (2):

$$M_i^t = \frac{D_i^t(x^{t+1}, y^{t+1})}{D_i^t(x^t, y^t)} \tag{2}$$

Based on Eq. (2), the change in the Malmquist index from period t to $t + 1$ can be measured, i.e., total factor productivity as shown in Eq. (3):

$$M_i(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left(\frac{D_i^t(x^{t+1}, y^{t+1})}{D_i^t(x^t, y^t)} \right) \left(\frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^{t+1}(x^t, y^t)} \right) \right]^{1/2} \tag{3}$$

x^t, y^t and x^{t+1}, y^{t+1} are the input-output vectors in two different periods, and D_i^t and D_i^{t+1} are the distance

functions in different periods. The input variables are labor input and capital input, where labor input is approximated by the number of employees in the urban commercial circulation industry, and capital input is estimated by the perpetual inventory method to estimate the capital stock of commercial circulation industry in each city. The output variables are measured by the value added of urban trade circulation industry.

- b. Independent variable: Digital City Competitiveness Index (*Dc*): based on the six-dimensional index system constructed in “Digital city competitiveness indicator measurements”, the entropy value method is used to determine the weight measurement, the specific results are detailed in Table 2.
- c. Control variables: Inspired by the research methodologies of Tian and Li (2022) and Yu and Chen (2020), this paper has chosen a series of control variables including: the economic development level of the city’s region, technological innovation level, openness to foreign trade, and the level of digital financial development. The economic development level of the region is approximated using the per capita GDP of the city, and this value is subjected to logarithmic transformation. Technological innovation level is gauged by the number of patents granted in the city, and this value too is logarithmically transformed. Openness to foreign trade is approximated by the amount of foreign direct investment in the city, with the value also being logarithmically transformed. The level of digital financial development is approximated using the Digital Financial Inclusion Index provided by the Digital Inclusive Finance Research Center at Peking University, and this value is logarithmically transformed.

For calculating the total factor productivity of the commercial circulation industry, data concerning labor input, capital input, and output variables are sourced from various editions of the China City Statistical Yearbook and China Population Statistical Yearbook. The data for the control variables come from editions of the China City Statistical Yearbook, the Wind Database, and the China Intellectual Property Office.

Empirical analysis

This study focuses on 15 of China’s new first-tier cities, spanning the years 2017–2021. Utilizing Stata 17 software, we first conducted a descriptive analysis of the sample data. The results indicate that the variance of the dependent variable, independent variable, and control variables is less than 0.4. The correlation coefficients between variables are all less than 0.5. The variance

inflation factors (VIF) range between 1.05 and 1.37, suggesting that there is no multicollinearity among the variables. Preliminary Hausman test results for the baseline regression analysis revealed a *P* value of 0.000, leading to the rejection of the null hypothesis. This favored the use of a fixed-effects model over a random-effects model. Consequently, we employed a two-way fixed-effects estimation to investigate the influence of digital city competitiveness on the total factor productivity of China’s urban commercial circulation industry. The empirical estimation results for the baseline regression are presented in Table 3.

Column 1 of Table 3 presents regression results without considering control variables. The findings indicate that the regression coefficient for digital city competitiveness on the total factor productivity of the commercial circulation industry is 0.1426, significant at a 1% statistical level. Columns 2 to 5 show regression results when progressively introducing control variables to gauge the impact of digital city competitiveness on the total factor productivity of the commercial circulation industry. According to the estimated results, digital city competitiveness has a significantly positive effect on boosting the total factor productivity of the commercial circulation industry. Moreover, the regression coefficient for digital city competitiveness is greater than that of other control variables. This suggests that enhancing digital city competitiveness aids in activating a city’s digital empowerment vigor, making urban infrastructure and transportation more intelligent and smart. This, in turn, can enhance the efficiency of the commercial circulation industry, reduce distribution costs, and promote a rise in the industry’s total factor productivity (Wen et al., 2022). The research hypothesis of this article is confirmed.

From an objective perspective, in recent years, as a crucial part of China’s new infrastructure development, there has been increased emphasis on the construction of digital urban infrastructure. In China’s first-tier cities, intelligent urban blocks, smart business districts, and automated delivery boxes have continuously emerged, significantly advancing the deep integration of new technologies such as artificial intelligence, the Internet of Things, blockchain, 5G with the commercial circulation industry. This has even spurred the growth of new e-commerce trends and modes, such as live-streaming commerce, interest-based commerce, and social commerce. These advances have expedited the digital transformation of the commercial circulation industry and enhanced its production efficiency. Based on the regression coefficients of the control variables, the level of technological innovation has the most substantial positive impact on the total factor productivity of the commercial circulation industry. This further corroborates the significant enabling role of digital city competitiveness on the industry’s productivity uplift in

Table 3 Estimated results of the effect of digital city competitiveness on total factor productivity of the commercial circulation industry.

	1	2	3	4	5
	<i>Tfp</i>	<i>Tfp</i>	<i>Tfp</i>	<i>Tfp</i>	<i>Tfp</i>
Digital city competitiveness	0.1426*** (3.67)	0.1263*** (3.85)	0.1193*** (2.78)	0.1037*** (2.76)	0.1173*** (2.04)
Regional economic development	-	0.0746*** (4.33)	0.0654*** (3.85)	0.0584*** (5.85)	0.0437*** (3.11)
Technology innovation level	-	-	0.0773*** (2.85)	0.0685*** (3.58)	0.05438*** (3.28)
External opening level	-	-	-	0.0443*** (2.67)	0.0362*** (4.38)
Digital inclusive finance development level	-	-	-	-	0.0284*** (4.85)
Region	Control	Control	Control	Control	Control
Time	Control	Control	Control	Control	Control
Constant term	0.8322*** (3.22)	1.0723*** (2.74)	0.7483*** (5.38)	2.1084*** (3.55)	1.6743*** (4.85)

Notes: The standard errors are in parentheses. The Time and Region indicators are included in the corresponding models, but their coefficients are not in this table. *** represent significance at 1, 5, and 10% levels, respectively.

Table 4 Digital City Competitiveness Index system measurements and data sources.

Digital city segmentation dimension	Specific indexes	Data sources
Urban information infrastructure construction	<ol style="list-style-type: none"> 1. Number of cell phone base stations/city population 2. Length of long-distance fiber optic cable lines/city population 3. Number of Internet broadband access ports 4. Number of ipv4 addresses per 100 people 5. Number of 5 G base stations 	<ol style="list-style-type: none"> 1. China Information Statistical Yearbook 2. China City Statistical Yearbook 3. China Science and Technology Statistical Yearbook
Urban governance capacity	Internet government service capabilities	Using the “Blue Book on Government Internet Service Capability: Report on the Development of Internet Service Capability of Local Governments in China” score approximate measure
Urban service capability	<ol style="list-style-type: none"> 1. Digital life: measured using the Digital Life New Services Index released in previous years; 2. Digital health care: measured using an approximation of the number of healthcare institutions in the city that have opened online healthcare services; 3. Digital transportation: approximated by the scale of the city’s investment in transportation infrastructure construction 4. Digital education: an approximation of the scale of the city’s investment in education 	<ol style="list-style-type: none"> 1. The new index of digital life services from the Internet Development Report of previous years; 2. China City Statistical Yearbooks and Statistical Bulletins; 3. CCID database
Urban industrial development	<ol style="list-style-type: none"> 1. City digital economy output value 2. Number of urban digital economy-related enterprises such as big data, blockchain and artificial intelligence in cities 	<ol style="list-style-type: none"> 1. China City Statistical Yearbooks 2. The number of enterprises is crawled according to the keywords “big data”, “blockchain” and “artificial intelligence”.
Urban innovation capacity	<ol style="list-style-type: none"> 1. R&D expenditure as a percentage of GDP 2. Number of granted patents 	<ol style="list-style-type: none"> 1. China City Statistical Yearbooks; 2. State Intellectual Property Office of China
Urban ecosystem	<ol style="list-style-type: none"> 1. Urban forest coverage rate 2. The proportion of days with excellent urban air quality index in the year 	<ol style="list-style-type: none"> 1. China Forestry and Grassland Statistical Yearbook 2. China City Meteorological Bureau statistics

a digital context. The regional economic development level, openness to foreign trade, and the development level of inclusive digital finance all contribute to elevating the total factor productivity of the commercial circulation industry.

To deepen the research findings, this study further compares the impact of different sub-dimensions of digital city competitiveness in China’s emerging first-tier cities on the total factor productivity of the urban commercial circulation industry. Initially, based on the six dimensions of digital city competitiveness outlined in Table 4, the entropy method was used to calculate the competitiveness index for each dimension in the sample cities across the years. These dimensions include: Urban Information Infrastructure Construction Index, Urban Governance Capability Index, Urban Service Capability Index, Urban Industrial Development Index, Urban Innovation Capability Index, Urban Ecosystem Index. These indices were then used as independent variables to regress against the total factor productivity of the urban commercial circulation industry, with the remaining variable definitions consistent with Eq. (1). Table 5 presents the estimated results of the impact of these six detailed dimensional indices on the total factor productivity of the urban commercial circulation industry. Given the length constraints, the estimated results of the control variables are not reported.

Table 5, columns one through six, respectively, report the regression results of the specific dimensions of digital city competitiveness on the total factor productivity of the urban commercial circulation industry. The results indicate that the regression coefficients of all six specific dimensions of digital city competitiveness on the total factor productivity of the urban commercial circulation industry have passed the significance test at the 1% statistical level. Among them, the regression coefficient of the urban ecosystem on the total factor productivity of the

commercial circulation industry is significantly negative, while the coefficients of the other dimensions are all significantly positive.

Urban information infrastructure construction has the most substantial positive impact on the total factor productivity of the commercial circulation industry, with a regression coefficient of 0.1535. When a city boasts robust information infrastructure, such as high-speed internet, advanced communication systems, and significant data centers, the efficiency of commercial circulation notably improves. This is because information flows rapidly, allowing for real-time decisions and transactions, subsequently enhancing the total factor productivity. Following are the urban industrial development capability, urban innovation capability, and urban service capability. The enabling effect of urban governance capability on the total factor productivity of the commercial circulation industry is relatively smaller, with a regression coefficient of 0.0947.

Conversely, the urban ecosystem does not provide a significant positive enabling effect on increasing the total factor productivity of the commercial circulation industry; instead, it has a suppressive effect, with a regression coefficient of -0.0432. Possible reasons could be overly strict environmental regulations in China’s emerging first-tier cities might have limited certain commercial activities. Alternatively, a focus on the ecosystem might have diverted resources from commercial circulation to other areas. Or, as a requirement for green, low-carbon development, the urban ecosystem often demands a greener transition in the commercial circulation industry. Such a transition to greener commercial circulation might necessitate more significant capital investment for renovations, inadvertently restraining the development of the urban commercial circulation industry, and resulting in a negative suppressive effect. However, this doesn’t

Table 5 Regression results of the sub-dimensions of digital city competitiveness on the total factor productivity of the urban commercial circulation industry.

	1	2	3	4	5	6
	<i>Tfp</i>	<i>Tfp</i>	<i>Tfp</i>	<i>Tfp</i>	<i>Tfp</i>	<i>Tfp</i>
Independent variables	Information Infrastructure Construction	governance capacity	Urban Service Capability	Urban Industrial Development	Innovation Capacity	Ecosystem
Regression results	0.1535*** (4.41)	0.0947*** (2.64)	0.1215*** (4.32)	0.1335*** (2.54)	0.1274*** (3.23)	-0.0432*** (-2.69)
Control variables	Control	Control	Control	Control	Control	Control
Region	Control	Control	Control	Control	Control	Control
Time	Control	Control	Control	Control	Control	Control
Constant term	1.3522*** (3.27)	0.6324*** (3.37)	0.9733*** (4.43)	1.6733*** (2.76)	1.1334*** (2.64)	0.8372*** (4.24)

Notes: The standard errors are in parentheses. The time and region indicators are included in the corresponding models, but their coefficients are not in this table. *** represent significance at 1, 5, and 10% levels, respectively.

imply that protecting the urban ecosystem is unimportant. In the long run, a healthy urban ecosystem can yield sustainable economic growth and a higher quality of life for cities. Overall, the results are generally in line with theoretical expectations.

Conclusions and insights

Digital urbanization is pivotal for cities evolving in the digital age and is bound to spur the high-quality growth of associated urban sectors. Key findings from this research include:

- a. Within the sampled emerging first-tier cities in China, there’s a notable variance in digital urban competitiveness. Ranking-wise, Hangzhou distinctly outpaces others in the Digital City Competitiveness Index, holding the premier position. Chongqing, Tianjin, Chengdu, Qingdao, Ningbo, Nanjing, and Wuhan form the second tier, with Suzhou, Xi’an, Dongguan, Changsha, Foshan, Zhengzhou, and Hefei in the third bracket.
- b. The digital prowess of China’s emerging first-tier cities markedly boosts the Total Factor Productivity in their commercial circulation industry (Li and Tian, 2023). Also, factors like regional economic progression, tech innovation, international openness, and the evolution of inclusive digital finance all positively impact this productivity. Among these, technological innovation stands out as the most significant enhancer.
- c. Various components of digital city competitiveness distinctly influence the Total Factor Productivity of the urban commercial circulation sector. Specifically, investments in urban information infrastructure play a pivotal role in boosting productivity (Canning and Pedroni, 2008). They’re followed by urban industrial growth capability (Rodríguez-Pose and Crescenzi, 2008), urban inventive aptitude (Glaeser et al., 1992), urban service proficiency (Canning and Pedroni, 2008), and governance expertise (Acemoglu et al., 2001). Conversely, urban ecological considerations hinder productivity growth within this sector.

This research establishes a significantly positive relationship between the digital city competitiveness of China’s emerging first-tier cities and the total factor productivity of their commercial circulation industry, providing profound insights into the relationship between digital city development and its economic benefits. Furthermore, this study elucidates the effects of different sub-dimensions of digital city competitiveness on the total factor productivity of the urban commercial circulation industry, offering a framework for future research to delve into the specific

impacts of each sub-dimension. Moreover, the conclusions of this study offer policy implications for decision-makers. Firstly, considering Hangzhou’s leading position in the Digital City Competitiveness Index, other cities could draw lessons from Hangzhou’s successful experiences, devising pertinent digital strategies to bolster their digital competitiveness. Furthermore, to enhance total factor productivity, cities should prioritize investments in information infrastructure (Canning and Pedroni, 2008), especially in communication equipment (Abor et al., 2018). In addition, fortifying a city’s industrial growth capacity, inventive prowess, service efficiency, and governance expertise is paramount to augmenting productivity. For instance, encouraging businesses to invest in R&D for technological innovation or fostering specific industries to centralize in certain areas to form industry clusters (Delgado et al., 2016), thereby capitalizing on economies of scale and complementary benefits, can significantly uplift industrial growth capacity. By subsidizing research institutions and fostering connections between local universities and international research entities (Bercovitz and Feldman, 2006), a city’s inventive capacity can be enhanced. The government should actively create employment opportunities for residents, provide training to guide them in the wise utilization of resources, with the goal of making the city serve the majority of its population (Kandpal and Studies, 2018). Service efficiency can be elevated through digital means, simplifying service processes, or by refining the proficiency of service personnel. Improving governmental transparency (Grimmelikhuijsen, 2012), instituting reforms, and stimulating public participation (Irvin and Stansbury, 2004) are among the ways to bolster urban governance. Lastly, although the study discerns that urban ecological considerations might impede the growth of productivity, it underscores the imperative for cities to strike a balance between ecology and economy, ensuring sustainable development in their pursuits (Hao et al., 2022).

This research focuses on China’s emerging first-tier cities as its primary sample and does not encompass smaller cities or rural areas within China. As a result, the findings may predominantly represent the specific contexts of these particular cities, suggesting caution when applying these results more broadly across the country. Moreover, with the rapid evolution of technology and the market, the timeliness of the research data could be challenged, necessitating continuous updates. Furthermore, the evaluation methods and sources used for the Digital City Competitiveness Index and the Total Factor Productivity might introduce biases or inaccuracies. In addition, the study may not have fully taken into account external factors such as national policies, international circumstances, and market trends that

could deeply influence the outcomes. In the future, there is potential to expand the sample to be more comprehensive, encompassing China's second and third-tier cities, and even rural areas, aiming to delve deeper into how digitization impacts various regions. It would also be valuable to longitudinally track the digital transformation trends of a city over consecutive years, providing insights into its long-term implications. Beyond the current focus on the commercial circulation industry, the effects of digital cities on other sectors, including manufacturing, education, and health care, warrant deeper exploration. An international perspective is equally essential, comparing China's digital cities with those in other countries can aid decision-makers in refining their developmental strategies.

Data availability

The city data for this study are sourced from the "China City Statistical Yearbook" available on the official website of the National Bureau of Statistics of China, with the database access URL being: <http://www.stats.gov.cn/>. The data are supplied in a supplementary file.

Received: 22 May 2023; Accepted: 14 November 2023;

Published online: 09 December 2023

Notes

- 1 The data is sourced from the "China Internet Development Report (2022)" released by the China Internet Association on September 14, 2022.
- 2 The "City Commercial Attractiveness Rankings 2023" released by the New First-Tier City Research Institute under China's renowned financial media, Yicai (also known as First Financial), on May 30, 2023, stated: In 2022, the combined population of China's 15 new first-tier cities reached 199 million, accounting for 14.1% of the country's total population. Against the backdrop of a nationwide population decrease of 850,000 in 2022, these 15 new first-tier cities witnessed a population increase of 1.0949 million. Overall, the new first-tier cities have become major population inflow hubs in China.
- 3 According to the "City Commercial Attractiveness Rankings" released by the China Emerging First-tier Cities Research Institute in May 2023: The 15 emerging first-tier cities in China in 2023 are Chengdu, Chongqing, Hangzhou, Wuhan, Suzhou, Xi'an, Nanjing, Changsha, Tianjin, Zhengzhou, Dongguan, Qingdao, Kunming, Ningbo, and Hefei.
- 4 The China Center for Information Industry Development (CCID), a direct affiliate of China's Ministry of Industry and Information Technology, released its "2022 Digital City Competitiveness Research Report" in November 2022. This report offers a comprehensive evaluation of the digital competitiveness of Chinese cities and delves into the strategies and methods of digital city construction. This paper draws upon the CCID's approach to constructing metrics for digital city competitiveness.

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Acknowledgements

This research received no funding.

Author contributions

All authors contributed equally to this work. The creation of this article was conducted by TianTian Meng, with significant encouragement and assistance from Dr. Danni Yu, who also helped with the review and revision of the manuscript. LuDi Ye assisted with the data analysis part. Dr. MH Yahya and Dr. MA Zariyawati offered guidance throughout the development of this paper.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1057/s41599-023-02390-7>.

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