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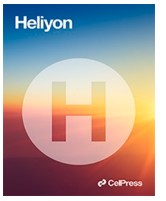

Spatial-temporally and industrially heterogeneous effects of new infrastructure construction on fostering emerging industries in Chinese cities

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ABSTRACT

New infrastructure construction stemming from the new waves of technological revolution worldwide is exemplified by 5G base stations, big data centers, and ultra-high voltage. It has aroused extensive academic and policy interests in recent years, especially due to its beneficial role in empowering regional novel economic dynamics. However, this argument is still too general to capture the nuanced effects of new infrastructure construction on fostering emerging industries in specific spatial-temporal and industrial contexts, which is left for geographers to take up. This paper focuses on the spatial-temporally and industrially heterogeneous effects of new infrastructure construction on fostering four distinctive emerging industries in major Chinese cities over the last decade. It reveals that new infrastructure construction and emerging industries have experienced rapid development in major Chinese cities, with geographical agglomeration in national central cities with advanced economic development level. It is empirically demonstrated that new infrastructure construction can facilitate the development of emerging industries in major Chinese cities, while significant spatial-temporal heterogeneity characterizes the contributory forces. Furthermore, artificial intelligence as a Key Enabling Technology, robotics as a kind of hardware-featured industry, software-*as*-a-service as a software-centered industry, and blockchain as a networking-oriented industry vary markedly in the extent and the ways in which they benefit from new infrastructure construction, and they consequently exhibit industrial sensitivity to spatial-temporal heterogeneity in the fostering effects.

1. Introduction

New infrastructure, exemplified by 5G base stations, big data centers, and ultra-high voltage driven by the new waves of technological revolution worldwide, is gaining prominence in both academic and policy circles [1–4]. First, the new waves of technological revolution physically give birth to new infrastructure that empowers the incubation of regional novel economic dynamics [5,6]. Second, under the increasingly fluctuant global and regional economy repeatedly hit by external shocks such as financial crisis, geopolitical tensions, trade conflicts, and COVID-19 pandemic over the last decade or so, new infrastructure is suitably utilized to stimulate fresh rounds of investment and technological innovation, thereby mitigating economic downturn and coping with

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uncertainties [2,4,7].

In contrast to the Western developed economies with passionate interests in building digital infrastructure for fueling regional digital and platform economy as well as narrowing digital gaps between urban and rural areas, China as a transitional socialist economy aims to develop a comprehensive new infrastructure system consisting of different subcategories in information, converged, and innovation infrastructures for smoothly implementing national strategies such as Chinese-type modernization, competitive urban agglomerations, and regional coordinated development [3,8,9]. For instance, digital infrastructure was originated from the engineering field in the Western world in the early 2000s, referring to interrelated networks composed of sensors, actuators, wired and wireless communication networks, and computer systems for civilian use [10]. Empirical cases of digital infrastructure have been expanded to cover physical digital infrastructure based on the application of next-generation information technologies [11], digitalized transport and urban infrastructures [12], and various types of digital platforms serving for residents' shopping, travelling, and entertainment, etc. [13]. By contrast, the notion of "new infrastructure" in China was initially proposed at the Central Economic Working Conference at the end of 2018, as a key underpinning for flourishing the mainland domestic market. Since then, it has been frequently and repeatedly deployed by the central and local governments as a strategic impetus for regional socioeconomic development. It is highlighted by the state that in short term, new infrastructure construction is designated as a means to sustain regional economic growth and adapt to external shocks, while in long term, more importantly, it is of strategic significance for building Chinese modern economic systems and achieving Chinese-type modernization in the post-pandemic era [14,15]. On April 20, 2020, the National Development and Reform Commission for the first time clearly defined new infrastructure as infrastructure systems led by new development philosophy, driven by technological innovation, based on information networks, for meeting the demands of high-quality development by offering services in the field of digital transformation, intelligent upgrading, and integrated innovation. Three subdivided constituents of new infrastructure are recognized to form a comprehensive new infrastructure system, including information infrastructure such as communication networks and computing power generated by new-generation information technologies, converged infrastructure as upgraded traditional infrastructure (e.g., transport and energy infrastructures) melting with new information technologies, and innovation infrastructure supporting scientific research, technological exploitation, and product development [8,9].

An increasing number of new infrastructure studies have been emerging over the past five years. On top of introductory and commentary literature revolving around the definitions, features, and dynamics of new infrastructure construction, its geographical pattern and consequent effects on facilitating regional industrial upgrading and structural transition have received ascending attention [16,17]. As for geographical distribution, existing studies tend to portray the locational patterns and influential factors of new infrastructure construction. Spatial agglomeration in socioeconomically leading regions and selective dispersion towards less-developed regions conditioned by a wide range of locational factors can largely characterize the geographical distribution and evolution of new infrastructure construction, with a remarkable hierarchical nature and urban-rural gaps [1,5,18]. Land and energy cost, socioeconomic development level, human capital, informatization degree, urbanization rate, and financial capacity are broadly examined as the key locational factors of new infrastructure construction [2,19,20].

In terms of regional economic development effects, new infrastructure functions as regional enabling assets for fostering emerging industries, upgrading established industries, and diversifying industrial composition [21]. Existing studies tend to empirically examine the effects of new infrastructure on facilitating regional industrial development. Leon (2018) confirms that the spatial data infrastructure construction in the European Union is conducive to fostering regional digital industries by forming a territorially unified digital market [22]. Rippa and Secundo (2019) propose the conceptualization of Digital Academic Entrepreneurship to specify the role of new infrastructure in stimulating new-technology start-ups and thus raising emerging industries in regions [23]. Guo et al. (2020) quantitatively examine the contribution of new infrastructure construction to regional industrial upgrading via mechanisms of facilitating technological revolution and increasing capital intensity [24]. Tranos et al. (2021) find out long-lasting positive effects of early adoption of digital technologies on regional productivity across the UK during 2000–2016 [25]. Based on provincial panel data for China during 2004–2019, Du et al. (2022) disclose that new infrastructure investment can dramatically optimize industrial structure and enhance production efficiency, although with noteworthy regional heterogeneity [15]. Relatedly, based on a provincial panel dataset during 2013–2018 in China, Wu et al. (2021) zoom in on synergetic dynamics between new infrastructure construction and emerging industries development, especially within the east coastal regions [8]. In a nutshell, existing literature reaches a broad consensus on the efficacy of new infrastructure construction in fostering emerging industries at the regional level and its spatial heterogeneity via assorted mechanisms and geographically diversified research cases.

Given the nascent state of geographical studies pertaining to the impact of new infrastructure construction on regional economic development, there are a couple of research gaps that have yet to be addressed. First, despite the benefits of new infrastructure construction on fostering emerging industries in regions that has been repeatedly highlighted, the effects of new infrastructure construction on fostering specific emerging industries and their industrial sensitivity are less unveiled. As it is commonly acknowledged, different emerging industries are characterized by distinctive technological bases and demands for infrastructure-relevant assets, the effects of new infrastructure construction need to consider the sector-specific nature [26,27]. Second, spatial heterogeneity of the role of new infrastructure construction in fueling emerging industries has attracted increasing attention, but temporal heterogeneity has not been sufficiently incorporated into research framework. Particularly for developing countries such as China, as it can be seen, both new infrastructure construction and emerging industries formation just took shape and fluctuated dramatically within the last decade or so, spatial-temporal heterogeneity in effects is assumed not to be insubstantial [3,28]. Third, geographical lens on new infrastructure construction as driving forces for emerging industries development has been mostly attached to the regional or provincial level, more fine-grained geographical analyses at the city level are yet to be enriched. Both new infrastructure construction and emerging industries are inclined to agglomerate in urban areas in contrast to non-urban areas, and co-location with geographical

proximity enables knowledge spillovers, technology transfer, and positive externalities [29,30].

Drawing upon the above research progress and theoretical debates, this paper aims to fill the research gaps by examining the spatial-temporally and industrially heterogeneous effects of new infrastructure construction on fostering four emerging industries (i.e., artificial intelligence, robotics, software-*as*-a-service, blockchain) in Chinese cities during 2011–2022. This study has the potential to shed fresh lights on more context- and industry-sensitive effects of new infrastructure construction on fostering emerging industries at the city level, as well as to offer policy implications for synergistically building new infrastructure and incubating emerging industries in major Chinese cities on one hand and striving for regional coordinated development across the national territory on the other.

The remainder of the paper is organized as follows. Section 2 introduces research design, data and methodology. It is followed by the empirical part, which is comprised of portraying the spatial-temporal development pattern of new infrastructure construction and emerging industries in major Chinese cities, examining spatial-temporally and industrially heterogeneous effects of new infrastructure construction on fostering four emerging industries in major Chinese cities, respectively. Section 6 discusses the empirical findings in a wider discourse and concludes the study.

2. Materials and methods

2.1. Research design

The development level of new infrastructure construction in a comprehensive manner in Chinese cities is measured according to the authoritative definition proposed by the National Development and Reform Commission in 2020. The evaluation system consists of information infrastructure indicated by the number of the internet broadband ports/clients and mobile internet users, converged infrastructure indicated by the length of expressway, autobus and trolleybus, and rail transport, and innovation infrastructure indicated by the number of R&D personnel, patent applications, and the amount of internal R&D expenditure. The four emerging industries cover artificial intelligence, robotics, software-*as*-a-service, and blockchain. First, the formation of the four emerging industries enjoys robust relatedness with next-generation information technologies and relies on technological innovation and spatial flows of resources that benefit from new infrastructure construction. Second, they stand for different types of emerging industries that to varying degrees depend on the empowerment of new infrastructure construction. Specifically, artificial intelligence is a Key Enabling Technology that penetrates into nearly all aspects of socioeconomic life, which is extensively interwoven with the comprehensive nature of new infrastructure construction in China [31,32]. Robotics as a hardware-driven emerging industry to a greater extent hinges upon the engineering-related characters and fixed assets of new infrastructure [33,34]. Software-*as*-a-service as a software-focused industry is featured by a higher level of technology input and knowledge production, which rests more with technological intensity and soft institutions of new infrastructure [35,36]. Blockchain is an underlying architecture that organizes and connects information distributed across decentralized physical nodes, particularly riding on the networking capabilities as well as geographically reached scope of new infrastructure [3,9].Concerning both data availability and case representativeness, this study selectively focuses on 21 major Chinese cities (e.g., Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu, Chongqing, Tianjin, Hangzhou, Suzhou, etc.) that possess leading positions in new infrastructure construction and emerging industries incubation [8,15]. It should be confessed that the 21 major cities cannot fully mirror the entire Chinese urban landscape, but they still can as far as possibly help to reveal the geographical pattern and spatial-temporal and industrial heterogeneity of the development effects by new infrastructure construction. The 21 major cities not only embrace rapid development of all four emerging industries, but also span across the east, middle, and west regions as well as different development levels of urban agglomerations in China. Since new infrastructure construction and emerging industries development are sensitive to territorial economic dynamics carved by geographical locations and the development level of urban agglomerations, both of them will be deployed as the ways in which spatial heterogeneity is manifested. The time-period in focus is during 2011–2022 when new infrastructure construction and emerging industries witnessed eye-catching development in major

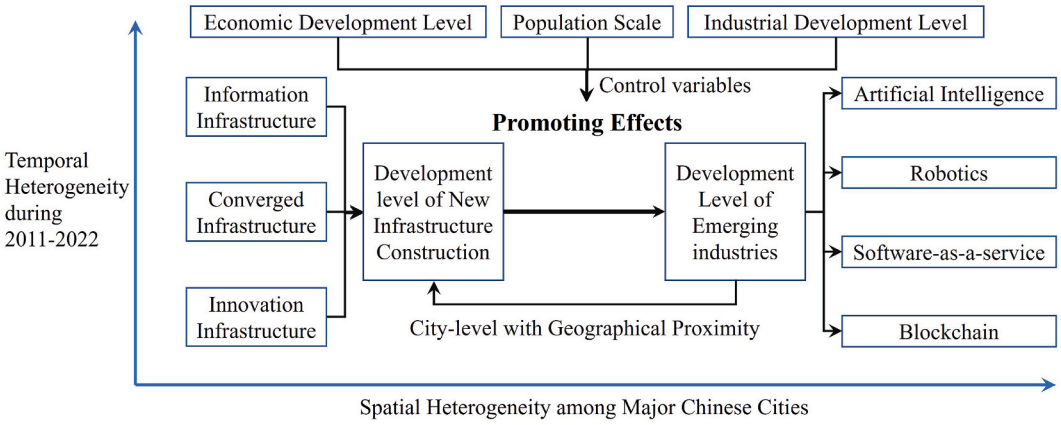

Fig. 1. Research framework.

Chinese cities. Considering the time lag effects of new infrastructure construction on fostering emerging industries in regions, the development level of emerging industries will be calculated three years later than that of new infrastructure construction, by referring to relevant policy documents in China. The overarching research framework is shown in Fig. 1.

2.2. Data and methodology

2.2.1. Data

The development level of new infrastructure construction in major Chinese cities in 2011, 2015, and 2019 is sourced from *China City Statistical Yearbooks*, *Statistical Bulletins on National Economic and Social Development*, and the Statistical Yearbooks of each city in relevant years. GDP, the number of permanent residents, and gross industrial output value above designated size (i.e., firm-level annual prime operating revenue over 20 million yuan) as control variables are sourced from the Statistical Yearbooks of each city as well. Suffering from the lack of official statistical datasets on emerging industries and their limited industrial output value at the embryonic stage, this paper takes advantage of the capability of attracting financial capital investment as an appropriate indicator for measuring the development level of emerging industries [37,38]. Therefore, the development level of four emerging industries is sourced from a proprietary database comprised of leading entrepreneurial high-tech firms attracting remarkable financial investments by a professional business information service provider in China, IT Orange. In total, 19,344 leading firms in four emerging industries are collected, including 4595 in artificial intelligence, 3672 in robotics, 3170 in software-*as*-a-service, and 7907 in blockchain. The financing volume in total of the artificial intelligence, robotics, software-*as*-a-service, and blockchain industries in each city by 2014, 2018, and 2022 is deployed to denote the development level of four emerging industries in major Chinese cities.

2.2.2. Methodology

According to the definition of new infrastructure by the National Development and Reform Commission in a comprehensive manner, the development level of new infrastructure construction in Chinese cities is measured as the weighted value of eight indicators representing the combination of information infrastructure, converged infrastructure, and innovation infrastructure based on the wide-used entropy weight method (EWM) [39]. It calculates the dispersion of value and assigns greater weight to the indicators of bigger dispersion as these indicators may contain more information. The measurement of new infrastructure construction is shown in equation (1), where $NI_{c,y}$ indicates the development of new infrastructure construction of city c in year y. $BD_{c,y}$ and $MI_{c,y}$ are the number of the internet broadband ports/clients and mobile internet user. $EW_{c,y}$, $PB_{c,y}$, and $RW_{c,y}$ are the length of expressway, autobus and trolleybus, and railway transport, respectively. $RDP_{c,y}$, $RDM_{c,y}$, $PT_{c,y}$ are the number of R&D personnel, patent applications, and the amount of internal R&D expenditure, respectively. $w_1 \sim w_8$ are the weights calculated by the EWM through the information entropy of each indicator.

$$NI_{c,y} = w_1 * BD_{c,y} + w_2 * MI_{c,y} + w_3 * EW_{c,y} + w_4 * PB_{c,y} + w_5 * RW_{c,y} + w_6 * RDP_{c,y} + w_7 * RDM_{c,y} + w_8 * PT_{c,y} \quad (1)$$

On the basis of the development level of new infrastructure construction, equation (2) is used to measure its effects on fostering emerging industries in major Chinese cities. *FA* is the development level of each emerging industry at the city level. *Pop*, *GDP*, and *Ind* are the controlled variables of the number of permanent residents, GDP, and gross industrial output value above designated size, respectively. α_1 indicates the effects of new infrastructure construction on fostering the development of emerging industries in major Chinese cities. Positive α_1 exhibits positive promoting effects and vice versa, while a greater absolute value of α_1 indicates more powerful effects of new infrastructure construction on fostering emerging industries in major Chinese cities. In a two-step empirical analysis, the model is in the first place applied to all cities across the timespan to capture the overarching promoting effects and subsequently applied to cities in different ways of geographical classification and particular years to reveal the spatial-temporal and industrial heterogeneity in the effects. Two ways of geographical classification of major Chinese cities are based on the traditional division of east, middle, and west regions and the development level of urban agglomerations stipulated in the 14th Five-Year Plan for National Economic and Social Development of China, respectively (Table 1). Equation (3) ~ (5) are the models given specific year y and geographical classification c to explore the spatial-temporally and industrially heterogeneous effects.

$$FA = C + \alpha_1 NI + \alpha_2 lnPop + \alpha_3 lnGDP + \alpha_4 lnInd + \varepsilon \quad (2)$$

$$FA_y = C + \alpha_1 NI_y + \alpha_2\ ln\ Pop_y + \alpha_3\ ln\ GDP_y + \alpha_4\ ln\ Ind_y + \varepsilon\ (y = 2014, 2018\ or\ 2022) \quad (3)$$

$$FA_c = C + \alpha_1 NI_c + \alpha_2\ ln\ Pop_c + \alpha_3\ ln\ GDP_c + \alpha_4\ ln\ Ind_c + \varepsilon\ (c = East, Middle\ or\ West) \quad (4)$$

Table 1
Geographical classification of major Chinese cities.

Division of east, middle and west regions		Development level of urban agglomerations	
East	Beijing, Tianjin, Jinan, Qingdao, Nanjing, Suzhou, Wuxi, Shanghai, Hangzhou, Xiamen, Guangzhou, Shenzhen, Dongguan, Zhuhai	Tier 1	Beijing, Dongguan, Guangzhou, Hangzhou, Hefei, Nanjing, Shanghai, Shenzhen, Suzhou, Tianjin, Wuxi, Zhuhai
Middle	Hefei, Wuhan, Changsha, Zhengzhou	Tier 2	Chengdu, Wuhan, Changsha, Chongqing
West	Xi'an, Chengdu, Chongqing	Tier 3	Jinan, Qingdao, Xiamen, Xi'an, Zhengzhou

$$FA_{c,y} = C + \alpha_1 NI_{c,y} + \alpha_2\ ln\ Pop_{c,y} + \alpha_3\ ln\ GDP_{c,y} + \alpha_4\ ln\ Ind_{c,y} + \varepsilon\ (c = T1, T2\ or\ T3) \quad (5)$$

3. Spatial-temporal development of new infrastructure construction and emerging industries in Chinese cities

3.1. Spatial-temporal development of new infrastructure construction

Generally, new infrastructure construction witnessed rapid progress in major Chinese cities during 2011–2019, as the development level on average in 2019 had been nearly threefold of that in 2011 (Table 2). Moreover, the annual growth rate during 2015–2019 is higher than that during 2011–2015, exhibiting that the new infrastructure construction in major Chinese cities embraced accelerated development over the last decade.

Continuous increase in the standard deviation value implies a geographically uneven development pattern. Advanced level of new infrastructure construction tends to agglomerate in the first-tier cities in the national urban hierarchy, such as Beijing, Shanghai, Shenzhen, Guangzhou, and Chongqing (Fig. 2). Less centralized cities are confronted with widening gaps with the first-tier cities, which represents a geographically selective nature of new infrastructure construction in major Chinese cities.

3.2. Spatial-temporal development of emerging industries

Overall, emerging industries experienced dramatic expansion in major Chinese cities during 2014–2022 (Fig. 3). The total amount of financing of the four emerging industries in 2018 is roughly 15 times of that in 2014, and continue to be doubled in 2022. The evolving growth rates reflect a two-stage process, in which the first stage during 2014–2018 witnessed remarkable scale expansion, and the second stage during 2018–2022 drops in growth rate and steps downward to more steady development. On the one hand, it conforms to the theoretical rationale of the industrial life cycle that emerging industries attract a rising number of entries and investments in the initial phase and then become more economically rational after rounds of fierce competition and market selection [40, 41]. On the other hand, dramatic restructuring of the global and local economic contexts in recent years under strained geopolitical tensions and COVID-19 pandemic exerts observable influences on the development of emerging industries in Chinese cities.

Geographically, emerging industries exhibit agglomerated development in national central cities, such as Beijing, Shanghai, Shenzhen, Guangzhou, Hangzhou, and Nanjing (Fig. 3). Along with sustained industrial formation and development, the geographical patterns have become more polarized and hierarchical, championed by a small number of leading cities. Similar to the geographical distribution of new infrastructure, first-tier cities have increasingly broadened development gaps with lower-level cities in emerging industries over the last decade. It is indicated that although major Chinese cities possessed parallel development level of emerging industries in the early 2010s, a small portion of central cities have gone through more successful incubation and development of emerging industries than the rest.

Different emerging industries are characterized by variegated spatial-temporal development features in major Chinese cities. Artificial intelligence as a Key Enabling Technology has undergone the most spectacular development, in contrast to robotics, software-*as*-a-service, and blockchain industries. Robotics zooming in on hardware has similar expansion rates with artificial intelligence, although with a smaller financing scale. Software-*as*-a-service relying on software technological inputs in turn shows slower growth

Table 2
Spatial-temporal development of new infrastructure construction in major Chinese cities, 2011–2019.

City	Development Level of New Infrastructure Construction		
	2011	2015	2019
Beijing	0.0318	0.0444	0.0610
Shanghai	0.0306	0.0398	0.0516
Guangzhou	0.0161	0.0238	0.0388
Shenzhen	0.0182	0.0252	0.0408
Tianjin	0.0101	0.0163	0.0250
Chongqing	0.0118	0.0231	0.0368
Hangzhou	0.0102	0.0132	0.0215
Nanjing	0.0079	0.0157	0.0248
Suzhou	0.0103	0.0154	0.0263
Wuxi	0.0058	0.0083	0.0104
Dongguan	0.0056	0.0066	0.0114
Zhuhai	0.0004	0.0031	0.0056
Jinan	0.0032	0.0051	0.0107
Qingdao	0.0051	0.0074	0.0128
Hefei	0.0026	0.0065	0.0121
Wuhan	0.0063	0.0110	0.0225
Changsha	0.0051	0.0078	0.0146
Zhengzhou	0.0037	0.0064	0.0122
Xiamen	0.0026	0.0036	0.0071
Xi'an	0.0055	0.0140	0.0152
Chengdu	0.0075	0.0151	0.0266

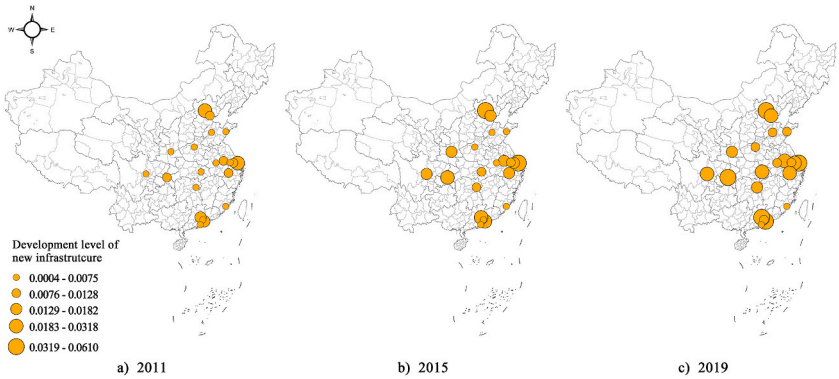

Fig. 2. Spatial-temporal development of new infrastructure construction in major Chinese cities, 2011–2019.

trends and less significant scale expansions. Blockchain saw explosive expansion during 2014–2018 but subsequently witnessed stagnation since 2018. Geographically, artificial intelligence is to the greatest degree agglomerated in leading cities (e.g., Beijing, Shanghai, Shenzhen), followed by blockchain championed by Hangzhou. Robotics presents a moderate level of geographical concentration, with Beijing and Shenzhen as the dual cores, while software-*as*-a-service tends to represent the most even geographical distribution pattern.

4. Temporally and industrially heterogeneous effects of new infrastructure construction on fostering emerging industries in Chinese cities

Based on the empirical results, it is verified that new infrastructure construction is beneficial to the incubation of emerging industries in major Chinese cities throughout the last decade (Table 3). Moreover, temporal and industrial heterogeneity evidently exists in the promoting effects.

Generally, new infrastructure construction can most effectively facilitate the development of the artificial intelligence industry in major Chinese cities, followed by robotics and software-*as*-a-service industries, whereas its empowering effects on the blockchain industry are insignificant to date. Distinctions among the promoting effects indicate that new infrastructure construction exerts variegated effects on fostering emerging industries with different characters. In terms of temporal heterogeneity, the effects of new infrastructure construction on fostering artificial intelligence, robotics, and software-*as*-a-service industries have been increasingly robust over time, except for the blockchain industry. Specifically, the effects on incubating the artificial intelligence industry are all the time the strongest, the coefficient value of 2018 is nearly thirty times of that in 2014, and then becomes about fourfold in 2022. Although the effects on fostering robotics and software-*as*-service industries are enhancing over time, their presentations of temporal heterogeneity are different. The positive effects on the software-*as*-a-service industry were stronger than the robotics industry in 2014, but in the following decade, the driving forces for robotics generated by new infrastructure construction surpassed that for software-*as*-a-service, implying that the new infrastructure construction in major Chinese cities stands out more substantially for hardware-centered emerging industries relying on fixed asset investments than software-related industries that are more technology-intensive and soft-institution-oriented. However, the positive effects on the blockchain industry only took shape in 2014 and gradually weakened afterward until present. It is presumably indicated that the role of new infrastructure construction in stimulating emerging industries for networking and integrating geographically distributed nodes has not been well performed yet in Chinese cities.

5. Spatial-temporally and industrially heterogeneous effects of new infrastructure construction on fostering emerging industries in Chinese cities

Spatial heterogeneity according to either the division of east, middle, and west regions, or the development level of urban agglomerations in the effects of new infrastructure construction on fostering emerging industries in major Chinese cities manifestly prevails (Table 4). Also, spatial-temporal and industrial heterogeneity among different emerging industries in the extent of promoting effects by new infrastructure construction has been validated. However, constrained by the limited number of cities in middle and west regions as well as in lower development levels of urban agglomerations, temporal heterogeneity within these regions cannot be quantitatively examined by the models (Table 4).

5.1. Artificial intelligence

New infrastructure, including improved computing power, enhanced data storage, network advancements, cloud and edge computing technologies, facilitates efficient training of complex artificial intelligence models, management of large data sets, and faster data transfer, thereby fostering the development of the artificial intelligence industry.

New infrastructure construction facilitates the development of the artificial intelligence industry most remarkably in cities in the

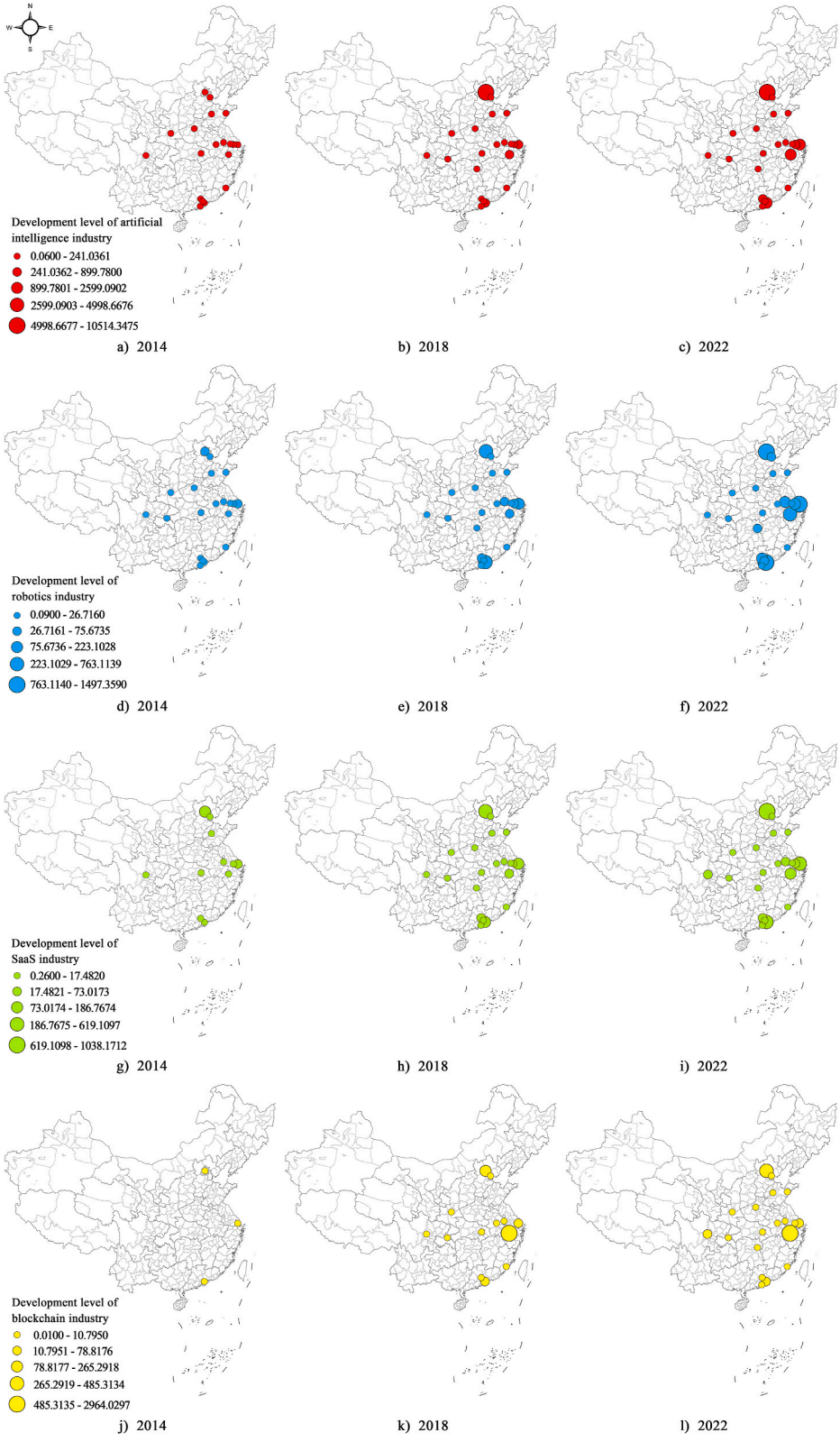

Fig. 3. Spatial-temporal development of emerging industries in major Chinese cities, 2014–2022.

Table 3
Temporally heterogeneous effects of new infrastructure construction on fostering emerging industries in major Chinese cities, 2014–2022.

Emerging Industries	Artificial intelligence		Robotics		Software-*as*-a-service		Blockchain	
	α_1	R^2	α_1	R^2	α_1	R^2	α_1	R^2
Overall	131700***	0.528***	22470***	0.626***	15380***	0.646***	−4429.99	0.046
2014	1060.71***	0.545***	238.76***	0.896***	604.53***	0.652***	37.30***	0.502**
2018	30160***	0.589***	3644.05***	0.678***	3991.37***	0.692***	−3113.68	0.043
2022	83870***	0.623***	13110***	0.775***	8426.36***	0.731***	−4325.17	0.052

Note: *, **, *** represent the significance level at 10 %, 5 %, 1 %, respectively.

Table 4
Spatial-temporally and industrially heterogeneous effects of new infrastructure construction on fostering emerging industries in major Chinese cities, 2014–2022.

City		Artificial Intelligence		Robotics		Software-*as*-a-service		Blockchain	
		α_1	R^2	α_1	R^2	α_1	R^2	α_1	R^2
East	Overall	98020***	0.601***	17220***	0.691***	11420***	0.73***	−8717.52	0.084
	2014	814.12*	0.629**	238.41***	0.924***	488.47**	0.767***	29.69*	0.622**
	2018	23960**	0.691**	2691.44*	0.718**	3190.43**	0.791***	−6958.63	0.103
	2022	63530**	0.693**	9913.13**	0.794***	6218.06**	0.779***	−8159.85	0.112
Middle	Overall	760.56**	0.714***	208.57	0.532	24.32*	0.912***	16.05***	0.874
	2014	/	/	/	/	/	/	/	/
	2018	/	/	/	/	/	/	/	/
	2022	/	/	/	/	/	/	/	/
West	Overall	−307.30*	0.857*	−49.20	0.879**	5.41	0.641	−6.30	0.525
	2014	/	/	/	/	/	/	/	/
	2018	/	/	/	/	/	/	/	/
	2022	/	/	/	/	/	/	/	/
T1	Overall	91240***	0.611***	18320***	0.69***	10870***	0.735***	−21760*	0.208
	2014	541.50	0.707**	249.98***	0.934***	422.75**	0.805**	22.80	0.702*
	2018	19660	0.704**	2926.89	0.695*	2862.04*	0.794**	−13580	0.258
	2022	56050	0.699*	11890**	0.797**	6015.22*	0.769**	−22550	0.403
T2	Overall	−301.13	0.774**	−206.03	0.508	43.43	0.636*	43.57	0.543
	2014	/	/	/	/	/	/	/	/
	2018	/	/	/	/	/	/	/	/
	2022	/	/	/	/	/	/	/	/
T3	Overall	123.60	0.633**	−5.13	0.684**	−97.07***	0.823***	8.34**	0.695**
	2014	/	/	/	/	/	/	/	/
	2018	/	/	/	/	/	/	/	/
	2022	/	/	/	/	/	/	/	/

east region that retain a relatively higher level of economic development, followed by the middle region, while it in turn prohibits the development of the artificial intelligence industry in cities in the west region. For the cities in the east region, the role of new infrastructure construction in the artificial intelligence industry has become more powerful steadily along time over the past decade. Although new infrastructure construction as well robustly pushes forward the development of the artificial intelligence industry in economically leading urban agglomerations, the temporal heterogeneity of it remains insignificant.

5.2. Robotics

The development of the robotics industry strongly requires a robust technological infrastructure for data management and high-speed communication, substantial investment in research and development, and skilled workforces.

The effects of new infrastructure construction on fostering the robotics industry mainly take shape in cities in the east region and senior development levels of urban agglomerations, but they do not present significance in middle and west regions and the second and third tiers of urban agglomerations. It reveals that the empowering role of new infrastructure construction in the robotics industry is more circumscribed in economically advanced cities, and the geographical dispersion of positive effects is still in its infancy. In addition to that, the driving forces of new infrastructure construction for the robotics industry in these regions have been persistently vigorous over time. A Matthew effect has been found across diversified types of regions in China, in terms of whether and to what extent new infrastructure construction facilitates robotics as a typical hardware-centered emerging industry.

5.3. Software-as-a-service

Improved internet enables efficient remote SaaS access. Cloud computing offers scalable on-demand resources, critical for broad SaaS delivery, while secure data store infrastructure assures data protection, making SaaS more accessible, reliable, and appealing.

New infrastructure construction can boost the development of the software-*as*-a-service industry in cities in east and middle regions, while the effects for cities in the west regions are hardly observable. In a similar vein, the positive effects of new infrastructure construction primarily engage in cities in east regions, with an intensifying trend over time. By contrast, the facilitation for the software-*as*-a-service industry in the middle region is much more attenuated. The effects for fostering the software-*as*-a-service industry in cities in the first-tier urban agglomerations are quite analogous to that in the east region. However, new infrastructure construction even has adverse effects on the development of the software-*as*-a-service industry in the lowest level of urban agglomerations, which merits further investigation on detailed causal mechanisms. In essence, the contribution of new infrastructure construction to the software-*as*-a-service industry as a technology-intensive emerging industry has already begun to geographically disperse towards relatively less-developed cities, although with less phenomenal trends than the artificial intelligence industry.

5.4. Blockchain

Advancements in digital infrastructure like high-speed internet, improved computing power, robust storage, and secure networking drive the progression and adoption of blockchain technologies, and hence foster its industrial formation and development.

Whether and to what extent new infrastructure construction fosters the formation and development of the blockchain industry in major Chinese cities are seemingly different from the other three emerging industries. Unexpectedly, new infrastructure construction does not perform as forceful dynamics for the blockchain industry in cities in economically advanced regions such as the east region and the first tier of urban agglomerations. Surprisingly, the blockchain industry in the middle region and the third tier of urban agglomerations in turn benefit the most from new infrastructure construction. To some extent, it manifests that new infrastructure construction is more effective in fostering the networking-oriented blockchain industry for industrial catch-up development and regional coordinated development, which is intriguing for facilitating a better understanding of the industrial sensitivity in spatial heterogeneity of the positive effects.

6. Discussion and conclusions

New infrastructure construction empowered by the new waves of technological revolution draws extensive attention for fostering regional novel economic dynamics across the globe. Earlier recovered from the COVID-19 pandemic, China strategically appointed new infrastructure construction as the potential catalyst of the new rounds of public and private investments, to perform as the seed incubating emerging industries and upgrading traditional industries in regions [3,14,15]. However, constructing new infrastructure to facilitate the formation and development of emerging industries in regions is still too general to capture the specific and grounded effects in detail. First, due to the initial development stage that both new infrastructure construction and emerging industries stand at and thus their rapidly changing trends over the last decade, the effects of new infrastructure construction on fostering emerging industries in regions are predictably fluctuating and unstable over time [8]. Second, the existence of a great degree of territorial differentiation in terms of economic development, fixed asset investment, and technological innovation, among others, in China renders the geographically heterogeneous effects of new infrastructure construction on fostering emerging industries in regions [42]. Third, although emerging industries share common characteristics (e.g., technology-intensive, environment-friendly, massive market potential), the extent and ways in which they are subject to new infrastructure construction vary markedly, as they may hinge upon either hardware-oriented, software-oriented, or networking-oriented aspects of new infrastructure construction which is in a quite comprehensive manner in China [3,30,43,44].

Key conclusions of this study are threefold. First, new infrastructure construction and four distinctive emerging industries including artificial intelligence, robotics, software-*as*-a-service, and blockchain have undergone rapid development in major Chinese cities over the past decade. They opt to geographically agglomerate in national central cities such as Beijing, Shanghai, Shenzhen, and Guangzhou, and the development gaps between the first-tier and lower-tier cities at the Chinese urban hierarchy have been enlarging over time, although different types of emerging industries exhibit variations under the identical roof. Second, it is indicated that new infrastructure construction in a comprehensive manner is positively associated with the formation and development of emerging industries in major Chinese cities over the last decade, with significant spatial-temporal and industrial heterogeneity engraving the beneficial effects. As for temporal heterogeneity, the positive effects have become increasingly powerful over time. In terms of geographical heterogeneity, the relational effects are rather significant in cities in economically advanced regions such as the east coastal region and economically leading urban agglomerations, in turn being marginalized in the middle region and even partially negative in least-developed cities. Third, different types of emerging industries in cities vary in the extent and ways in which they benefit from new infrastructure construction, therefore exhibiting further industrial sensitivity to spatial-temporal heterogeneity. The artificial intelligence industry standing for a Key Enabling Technology in the east region and advanced urban agglomerations has been facilitated to the greatest degree by new infrastructure construction, along with reinforcing impetus over time. Robotics as a kind of hardware-featured industry profits from new infrastructure construction only if they are located in economically advanced regions. The positive effects are more geographically circumscribed and reinforced over time as well. Software-*as*-a-service as a software-centered emerging industry is examined to be incubated by new infrastructure construction in a more extensive geographical scope, along with enhancing trends over time. However, preliminary results indicate that blockchain as a networking-oriented emerging industry only gains development momentum from new infrastructure construction when it is located in the middle region and less-developed urban agglomerations, prospectively laying the ground for regional coordinated development.

This paper examines the spatial-temporally and industrially heterogeneous effects of new infrastructure construction on fostering four emerging industries in major Chinese cities, aiming to offer more fine-grained geographical insights on the associational

relationships between city-level new infrastructure construction and the formation and development of emerging industries. As a preliminary and exploratory study, it serves for paving the way for the forthcoming studies to probe into more specific causal mechanisms that bridge subtypes of new infrastructure construction with diversified emerging industries with spatial-temporal and industrial sensitivity. Meanwhile, it should be admitted that there are several deficiencies of this study that need to be remedied in the follow-up scholarly efforts. First, as for the evaluation system of the development level of new infrastructure construction in Chinese cities, the eight indicators measuring the combination of information, converged, and innovation infrastructures are indirect and incomplete due to data constraint, which should be complemented with direct infrastructure-relevant data sources. Second, this paper deploys regression models to examine the effects of new infrastructure construction on fostering emerging industries in major Chinese cities, but hardly specifies underlying causal mechanisms connecting them, thus calling for a step further in data and methodological innovation. Third, suffering from the lack of new infrastructure data in statistical yearbooks of small-and-medium-sized cities, this study only utilizes a limited sample of major Chinese cities, which deserves to be expanded to cover the entire national territory by enriching closely matched data sources on city-level new infrastructure construction.

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Data availability Statement

The data that support the findings of this study are available on request from the first and corresponding authors.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Jili Xu: Writing - review & editing, Writing - original draft, Formal analysis, Conceptualization. **Guan Huang:** Writing - review & editing, Software, Methodology. **Yuyao Ye:** Writing - review & editing, Supervision, Funding acquisition. **Zhengqian Liu:** Visualization, Software.

Declaration of competing interest

None.

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