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A Study on the Evolution Characteristics and Key Drivers of Urban Entrepreneurial Ecosystem: From the Perspective of Complexity Science

Peng Xiong*, Lingli Qing

Graduate School of Management of Technology, Pukyong National University, Busan, Korea

Email address:
11675512@qq.com (Peng Xiong), 104869242@qq.com (Lingli Qing)

*Corresponding author

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Abstract: Entrepreneurial activity is a typical complex social system with significant regional heterogeneity. Most of the existing studies focus on explaining a certain aspect of entrepreneurial activities or exploring the extent to which regional entrepreneurial activities promote regional economic growth. However, examining regional entrepreneurial activities from a systematic rather than fragmented perspective may be able to reflect their internal and external quality more comprehensively and accurately. The purpose of this paper is to study the key factors affecting the quality of entrepreneurial activities in large Chinese cities based on the theories of "Entrepreneurial Ecosystem" and "Complexity System", and put forward corresponding recommendation on policy design and policy implementation. Based on a systematic review of studies on city-level entrepreneurial ecosystems and the application of complexity science in entrepreneurial research, The Urban Entrepreneurship Ecosystem Index (UEEI) system is constructed, which consists of three dimensions of synergy, emergence and phase change, 10 first-level indicators and 40 second-level indicators. The cross-section data of 2018 are used to make quantitative analysis on China's top ten quasi-first-tier cities such as Wuhan and Chengdu. The results show that the urban entrepreneurial ecosystem is characterized by coordination, emergence and phase transformation, and the more balanced the three characteristics are, the higher the quality of the urban entrepreneurial ecosystem will be. In terms of specific indicators, employment, technological innovation and education are the key order parameters, and the performance of a key order parameter is particularly excellent, which is a common characteristic of high-quality urban entrepreneurial ecosystem.

Keywords: Entrepreneurial Activity, Entrepreneurial Ecosystem, Complexity Science

1. Introduction

The research on the role of entrepreneurship in promoting economic growth can be traced back to the Schumpeter period. Due to the significant heterogeneity of entrepreneurial activities, the role of entrepreneurship in promoting regional economic growth is also significantly different. Entrepreneurial activities are both the cause of economic growth and the result of economic growth. The two-way causality makes research on the evaluation of the quality of entrepreneurial activities and its role in promoting the economy still in the stage of contention.

Scholars have reached a preliminary consensus. Due to the differences in production efficiency and innovation ability among regions, not all types of entrepreneurial activities can promote economic growth to the same extent under different institutional backgrounds. The same entrepreneurial activities have obvious and different marginal utility in different geographical regions. It is still a challenging task to explain how various factors promote regional economic growth through complex interactions and to what extent [1, 2].

The concept of "entrepreneurial ecosystem" that has emerged in recent years provides a biological metaphor for entrepreneurial activities, which vividly reflects the root of the complexity of entrepreneurial activities---non-linearity, that is, the mutual influence and interaction between various

entities in entrepreneurial activities, showing a non-linear relationship, the external input and system output do not conform to the superposition principle. As a holistic research method, the evaluation of the operating status of the entrepreneurial ecosystem in a specific area can objectively reflect the quality of entrepreneurial activities in this regional environment, and it can also directly reflect the impact of entrepreneurial activities on regional economic growth.

Based on the definition of geographic boundaries of urban, regional and national entrepreneurial ecosystems, this paper focuses on the measurement of urban entrepreneurial ecosystems in the Chinese context. The Urban Entrepreneurship Ecosystem Index (UEEI) is constructed to measure the quality of urban entrepreneurial activities in the Chinese context. The rationality and practicability of the index system are verified through the evaluation and analysis of panel data of 10 provincial capitals with rapid development and good economic foundation in different regions of China. The analysis results have some enlightenment for policy makers and entrepreneurs.

2. Literature Review

2.1. A Review of Research on Urban Entrepreneurial Ecosystems

As early as 1982, Pennings pointed out that the behaviors of entrepreneurs could not be explained only by rational economic models. When choosing different cities as business locations, they would consider not only the local economic conditions, but also many non-economic conditions. The integration of economic and non-economic indicators provides a multi-dimensional perspective for the study of entrepreneurial activities, which can explain the entrepreneurial ability of a city more objectively and truly. Since then, scholars have followed this multi-dimensional research concept and conducted research on the urban entrepreneurial ecosystem from both internal and external aspects.

Research on the internal aspects of the urban entrepreneurial ecosystem mainly focuses on the factors affecting entrepreneurial activities, and the representative research results are shown in Table 1.

Table 1. *Influencing factors of urban entrepreneurial activities.*

NO.	Proposer	Influencing factors/measurement variables
1	Erik Stam Andrew van de Ven (2019) [3]	1) Quality of government governance: corruption, rule of law, government effectiveness and accountability; 2) New companies: Percentage of new companies registered per thousand people; 3) Accessibility: Number of roads, railways and airports; 4) Demand: average purchasing power, regional products, total population; 5) Innovation cooperation: Proportion of enterprises carrying out innovation cooperation; 6) Leadership: Number of innovation program leaders per 1,000 companies; 7) Education: Percentage of adults with higher education; 8) Venture capital: Amount of venture capital per 1000 companies; 9) R&D: Percentage of GDP; 10) Business services: percentage of service-oriented companies in the business population.
2	X. Q. Xie, J. J. Huang (2017) [4]	1) Pressure: resident population, city's fiscal revenue, total investment in fixed assets, consumer price index, annual per capita disposable income of urban residents, annual per capita consumption expenditure of urban residents; 2) Status: total number of high-tech enterprises, total output value of high-tech industries, patent authorizations, registered scientific and technological achievements, technical contract transactions, loans from financial institutions; 3) Response: R&D expenditure, education expenditure, science and technology expenditure, social security and employment expenditure, public service expenditure, aviation civil airlines, road mileage, Internet broadband and fiber optic users.
3	Wei (2018) [5]	1) Pressure: resident population, city's per capita fiscal revenue, city's per capita total investment in fixed assets, consumer price index, urban residents' annual per capita disposable income, urban residents' annual per capita consumption expenditure; 2) Status: Total number of high-tech enterprises per million people, patent grants per million people, registered scientific and technological achievements per million people, per capita technology market turnover, loans from per capita financial institutions; 3) Response: R&D expenditure per capita, education expenditure per capita, science and technology expenditure per capita, social security and employment expenditure per capita, public service expenditure per capita, highway mileage per 10,000 square kilometers, Internet broadband access users per 10,000 people.
4	Martin Hemmert et al. (2019) [6]	1) Agglomeration size: population, GDP, number of enterprises; 2) Entrepreneurship ecological attributes: number of newly established companies, number of unicorns, type of industry, growth rate; 3) Entrepreneurial attributes: average age, percentage of female entrepreneurs, percentage of immigrant entrepreneurs, percentage of multiple entrepreneurs.
5	David B. Audretsch Maksim Belitski (2016) [7]	1) New Enterprises: New Enterprises Percentage in City; 2) Culture and norms: sense of safety in the city where you are located, sense of safety in the surrounding cities, percentage of trustworthy people around; 3) Infrastructure: Satisfaction with accessibility, satisfaction with urban greenery, satisfaction with urban tidiness, satisfaction with cultural facilities; 4) Internet Convenience: Satisfaction with Internet Services; 5) Formal system: percentage of people who think the government is responsible, percentage of people who think administrative agencies are helpful for entrepreneurial activities; 6) Inclusivity: foreigners comfortable integration proportion; 7) Demand: proportion of housing demand, proportion of finding a good job; 8) GDP: GDP by PPP.
6	EU REDI (2013) [8]	1) Entrepreneurial attitude: cultural support, networking, risk acceptance, entrepreneurial skills, opportunity perception; 2) Entrepreneurial skills: collaboration, human resources, technology applications, opportunity-based entrepreneurship; 3) Entrepreneurship desire: convenience of financing, degree of globalization, high growth, process innovation ability, product innovation ability.

In addition, scholars have also done a lot of research work on the participants in the urban entrepreneurial ecosystem and the relationship between them. In urban entrepreneurial activity, the efforts of individual entrepreneurs and the external environment are equally important, and the creation of a regional environment conducive to entrepreneurship and economic development determines the character of a city [9]. In different cities of the same country, the average annual number of start-ups varies greatly. The more developed the economy, the more the average annual increase of start-ups, the higher the proportion of opportunity entrepreneurship and the higher the proportion of local entrepreneurship [10].

Entrepreneurial behavior is strongly influenced by the urban environment in which they are located and has a direct positive or negative effect on their entrepreneurial attitudes, aspirations and opportunities; in addition, the local environment can determine whether the type of startup is more demand-driven or opportunity-driven, and has a significant impact on their growth rate. At the cultural level, the influence of successful entrepreneurs on potential entrepreneurs is significant, and the power of their words, actions and role models helps potential entrepreneurs learn entrepreneurial knowledge and management experience, and also eliminates potential entrepreneurs' fear and uncertainty to a certain extent [3].

As the two most important participants in the entrepreneurial ecosystem, the relationship between enterprises and the government is particularly complex. Enterprises benefit from both government governance and official corruption, while entrepreneurs' social networks can only make up for some institutional defects. Therefore, the entrepreneurial constraints caused by corruption are still very obvious in some cities [11]. Government regulatory regimes significantly influence the type and growth of entrepreneurial ventures and have a profound impact on regional entrepreneurship [12]. The regional entrepreneurial spirit precipitated in the historical development process has obvious continuity and stability, and its impact on regional entrepreneurial activities will last for decades or even longer [13]. Research on external aspects of urban entrepreneurial ecosystems has focused on the positive and negative externalities affecting regional and urban entrepreneurial activity. Empirical research shows that the knowledge spillover theory of entrepreneurship is also applicable to regions and industries. Universities and large high-tech enterprises have significant knowledge spillover effects on surrounding regions. The number of start-ups in these regions is significantly higher than that in other regions, because knowledge spillover promotes creative individuals to choose to become entrepreneurs, or promote entrepreneurs to recognize new entrepreneurial opportunities and commercialize them. What plays a decisive role in knowledge spillover is the number of universities, the total population and the increased number in cities [14].

2.2. A review of Complexity Theory Research in Entrepreneurial Activity

According to the famous Chinese scientist Qian Xuesen's reclassification of systems, the social system has many subsystems, complex relationships between hierarchical structures, and the influence of factors such as human participation, learning and adaptation. It is a typical, special and complex giant system. Although there is far from a consensus among scholars on the definition and research areas of complexity science, in general, complexity science offers a new perspective and a new integrated approach to the study of various disciplines, i.e. it requires scholars to pay more attention to the integrity of the object of study, to the connectedness of the elements that make up the system of the object, and to the non-superimposing incremental nature of the parts that make up the whole.

Entrepreneurship research is a field that has deep roots in complex science. Since Bygrave applied chaos theory to explain entrepreneurship theory in 1989, scholars have re-examined all aspects of entrepreneurial activities from various perspectives of complexity science and have come up with some new understandings. The reason is that the research of entrepreneurial activity and complexity science requires innovation, novelty, and newness [15], and complexity theory and its constituent concepts can provide some meaningful insights into entrepreneurial-related knowledge phenomena, and provide possible explanations for them [16]. Entrepreneurial activity and regional economic development is undoubtedly a complex system with dynamic nature, and the participating subjects within it constitute a network that interacts with each other in a nonlinear manner, and the dynamic equilibrium process of interdependence and mutual influence among the subjects can be better explained by using the theory of co-evolution in complexity science [17]. Whereas the business environment in which the entire entrepreneurial activity takes place is composed of a series of relationships between agents and stakeholders, and this network of relationships can change significantly due to human subjectivity, a key factor in complex systems, most factors in complex systems do not change the overall characteristics of the network of relationships [18], which is in line with the nature of the key sequential covatiates of synergy theory.

As a foundational feature of complexity science and a source of complexity, emergence theory emphasizes the circumstances under which and how a new order emerges, and the creation of new enterprises is undoubtedly one of the manifestations of new order establishment, a classic form of creative destruction [19]. In contrast, the entrepreneurial process of a single firm can be seen as a temporary change in the overall complex system, a process that breaks the original economic equilibrium to a considerable extent, injecting a new economic order into the complex system in the form of technological innovation, organizational and process innovation, business model innovation, etc. [20]. Phase change is the fundamental reason why complex systems are in a non-equilibrium state and refers to the overall, qualitative, macroscopic changes in the system due to quantitative changes in each participating subject or subsystem, i.e. phase change [21]. The phase transition of the system as a whole is sometimes fast and violent, sometimes slow and mild, but at the critical moment when the phase transition is about to be reached there are some parameters that show significant anomalies, and the body (subsystem) that has these parameters will benefit more from the phase transition of the complex system [22, 23]. According to this theory, in a rapidly changing external environment, companies that employ an aggressive and disruptive strategy are more likely to succeed because this strategy is more in line with the overall system characteristics and more likely to capture entrepreneurial opportunities; in a smoothly changing external environment, traditional strategies and formal planning activities are more

conducive to company success. Therefore, adaptation to the external environment, or the external environment, is crucial for the development of a business, especially a start-up [24, 25].

3. Construction of an Urban Entrepreneurial Ecology Index Based on a Complex Science Perspective

In addition to its biological metaphorical meaning, the term "entrepreneurial ecosystem" more importantly reflects the basic characteristics of entrepreneurial activities as a complex system, namely, the large number of participating actors, the complex non-linear interactions among them, and the nested levels of time, space and function. These characteristics also determine the three features of complex systems embodied in the entrepreneurial ecosystem: synergy, emergence and phase change.

Synergy is a fundamental feature of the entrepreneurial ecosystem, and co-evolution is an inevitable response of the system's enterprises and other participating agents in a competitive situation. By cooperating with other firms to complement each other, it can enable both or more parties to achieve better development of themselves at a smaller cost. The theory of synergism suggests that in the evolution of a complex system, a small number of slowly changing sequential covariates instead determine the overall characteristics and evolutionary direction of the system. Accordingly, the parameters related to enterprises, especially startups, in the entrepreneurial ecosystem can be selected as key sequential parameters to reflect the synergistic pattern of the whole entrepreneurial ecosystem, and then judge the overall quality of the system.

Emergence is the source of the complexity of the entrepreneurial ecosystem. The interaction between enterprises, policy makers and various service providers constituting a whole leads to a holistic character that is greater than the simple sum of the subsystems, i.e., the contribution of the entrepreneurial ecosystem as a whole to the regional economy is greater than the simple sum of the single contribution of each enterprise in the system, which is the greatest value of the existence of the entrepreneurial ecosystem. However, it is important to emphasize that emergence is a characteristic unique to the system as a whole and not possessed by individual subsystems. Factors that influence emergence generation include: participating subjects, self-organization, and the external environment. Participating subjects are the necessary conditions for emergence generation, and are the most critical agents of emergence generation, such as workers or entrepreneurs in the entrepreneurial ecosystem are the main participating subjects. The "convergence effect" generated by the self-organizing behavior of the subjects directly leads to the emergence of the emergence, which is the source of power generation of the emergence. This self-organization is not chaotic and disorderly, but has to follow certain rules and restrictions, such as economic and geographical conditions, transportation, hardware facilities, etc. Therefore, this self-organization is restricted generation. In addition, emergence requires the right external environment, both as a system as a whole and as component subsystems, which constantly need to interact with the external environment. The external environment, such as education, municipalities, transportation, etc., provides the energy needed for the evolution of the complex system and imposes significant constraints, thus forcing the complex system to further adapt to the external system, readjusting its internal structure and operating mechanism, and ultimately realizing the "emergence" of the whole over the sum of its parts.

Phase change is a universal characteristic of complex systems, and the prerequisite for its creation is that the system must be able to establish exchange relations with the external environment and be open, so that it can contribute to the internal equilibrium of the system and reach the critical state of phase change. In terms of this theory, the urban entrepreneurial ecosystem is always in a state of dynamic equilibrium, and only when internal and external factors work together to make the system reach a critical state will the overall "phase" of the system change, and this critical moment is often accompanied by some abnormal changes in parameters. The more complex the system is, the slower and more stable the phase change is. According to the entrepreneurial S-curve theory, the entrepreneurial ecosystem will go through three stages: factor-driven, efficiency driven and innovation-driven, and its construction and evolution cannot be achieved overnight, but requires a longer period of time to settle. In this process, the technological innovation results generated by entrepreneurial activities and the indicators related to promoting economic development and improving the living standard of residents can be used as the key parameters of the overall system "phase change".

In summary, based on the perspective of complexity science, the Urban Entrepreneurship Ecosystem Index (UEEI), which consists of 10 primary indicators and 40 secondary indicators, is constructed from three dimensions of synergy, emergence and phase change, as shown in Table 2.

Table 2. *City Entrepreneurship Ecological Index Measurement Indicators.*

Dimension	Tier 1 indicators	No.	Secondary Indicator	Unit	Number
Synergy	Population	1	Total population	10,000 people	C01
		2	Population growth rate	%	C02
		3	Number of R&D staff	People	C03
		4	Number of cell phone users	10,000 families	C04
		5	Number of Internet broadband access subscribers	10,000 families	C05
	Enterprise	6	Foreign direct investment contract projects	pcs	C11
		7	Actual amount of foreign capital used in the year	10,000 $	C12

Dimension	Tier 1 indicators	No.	Secondary Indicator	Unit	Number
		8	Number of industrial enterprises above the scale	pcs	C13
		9	Total profit of enterprises above the scale	10,000¥	C14
		10	Total retail sales of social consumer goods	10,000¥	C21
	Demand	11	Number of wholesale and retail trade enterprises	pcs	C22
		12	Import of goods	10,000¥	C23
		13	Proportion of tertiary industry	%	C24
		14	Number of general higher education schools	pcs	C31
	Education	15	Number of full-time teachers in general higher education institutions	People	C32
		16	Number of general undergraduate and college students	People	C33
		17	Education Expenses	10,000¥	C34
		18	Total investment in municipal construction	10,000¥	C41
Emerge	Municipalities	19	Sales area of commercial properties	10,000 sqm	C42
		20	Local general public budget revenue	10,000¥	C43
		21	Social electricity consumption	million kWh	C44
		22	Total annual bus passenger traffic	10,000 people	C51
	Transportation	23	Number of actual cabs at the end of the year	Vehicle	C52
		24	Road, water and air passenger volume	Vehicle	C53
		25	Road, water and air freight volume	10,000 ton	C54
		26	Gross regional product (current year prices)	10,000¥	C61
	Economy	27	GDP per capita	¥	C62
		28	GDP growth rate	%	C63
		29	Science and technology expenditures	10,000¥	C71
	Technology	30	R&D internal expenditure	10,000¥	C72
	Innovation	31	Patent Applications	pcs	C73
		32	Patents granted for inventions	pcs	C74
Phase change		33	Number of employees in urban units	People	C81
		34	Number of urban self-employed and private employees	People	C82
	Employment	35	IT industry employment	People	C83
		36	Registered urban unemployment	People	C84
		37	Average wage of employees	¥	C85
		38	PM2.5	μg/m³	C91
	Environment	39	Urban construction land area	sq km	C92
		40	Greening coverage of built-up areas	%	C93

4. Evaluation Analysis

4.1. Data Collection

The quality of entrepreneurial activity in cities has a significant positive correlation with the level of economic development of the city. Considering that the level of economic development varies greatly among provinces (municipalities directly under the central government) and different regions within provinces in China, comparative analysis at the provincial level or among cities with large disparities has limited significance for mutual reference. Based on this consideration, this study selects 10 "quasi-first-tier" provincial capitals, namely Shenyang, Nanjing, Hangzhou, Hefei, Zhengzhou, Wuhan, Changsha, Chengdu, Kunming, and Xi'an, which are recognized by society as being in the middle and upper reaches of the country, according to the economic development level of each provincial capital city in China in recent years. According to the indicators listed in Table 2, the data of the above 10 cities in 2018 were collected from authoritative statistical reports such as China City Statistical Yearbook 2019, China Torch Statistical Yearbook 2019, China Statistical Yearbook 2019, China High Technology Industry Statistical Yearbook 2019 and National Enterprise Innovation Survey Yearbook 2019, as shown in Table 3.

Table 3. *Data sheet of 10 cities in 2018.*

No.	Secondary index	Serial number	Shenyang	Nanjing	Hangzhou	Hefei	Zhengzhou
1	Total population	C01	746	697	774	758	864
2	Population growth rate	C02	-0.52	5.34	6.91	15.43	11.7
3	Number of R&D staff	C03	54179	129400	92897	86032	78797
4	Number of cell phone users	C04	1318	1284	1801	1007	1592
5	Number of Internet broadband access subscribers	C05	238	452	509	315	430
6	Foreign direct investment contract projects	C11	162	627	744	140	82
7	Actual amount of foreign capital used in the year	C12	143097	385339	682658	323000	421080
8	Number of industrial enterprises above the scale	C13	1453	2556	5431	2287	2686
9	Total profit of enterprises above the scale	C14	2983000	8949600	9387351	2402497	4528100
10	Total retail sales of social consumer goods	C21	40512312	58324550	57153259	29767420	42680900
11	Number of wholesale and retail trade enterprises	C22	1606	3085	4459	1347	1935
12	Imports of goods	C23	6421482	18165160	18281654	8271521	15278657
13	Proportion of tertiary industry	C24	58.1	61.04	63.9	50.28	54.67

No.	Secondary index	Serial number	Shenyang	Nanjing	Hangzhou	Hefei	Zhengzhou
14	Number of general higher education schools	C31	47	53	40	50	61
15	Number of full-time teachers in general higher education institutions	C32	26564	51765	30247	27073	51083
16	Number of general undergraduate and college students	C33	391152	726728	431965	497131	993479
17	Education Expenditure	C34	1152055	2530631	3154350	1635053	2129214
18	Total investment in municipal construction	C41	3016000	1346168	4752369	1685889	5032424
19	Sales area of commercial properties	C42	1355	1221	1676	1390	3712
20	Local general public budget revenue	C43	7206425	14700152	18250616	7124862	11520568
21	Social electricity consumption	C44	3574457	6064005	7969558	3448296	5603221
22	Total annual bus passenger traffic	C51	110200	88750	153729	55449	94000
23	Number of actual cabs at the end of the year	C52	17544	13354	13714	9402	10908
24	Road, water and air passenger volume	C53	15163	9551	11983	8041	9049
25	Road, water and air freight volume	C54	82939	91347	671489	34143	340779
26	Gross regional product (current year prices)	C61	62923981	128204000	135091508	78229061	101433173
27	GDP per capita	C62	75766	152886	140180	97470	101349
28	GDP growth rate	C63	5.41	8.0	6.72	8.54	8.3
29	Science and technology expenditures	C71	181126	805440	1182090	919741	361748
30	R&DInternal expenditure	C72	1687755	4165800	4643000	2566521	1852996
31	R&D internal expenditure	C73	23826	99020	98396	65814	70128
32	Patent Applications	C74	2943	11090	10267	5597	10654
33	Patents granted for inventions	C81	1182341	2191563	2791875	1832891	1879346
34	Number of employees in urban units	C82	1988990	4852270	4380227	1462900	2085738
35	Number of urban self-employed and private employees	C83	23905	186841	160400	48843	52964
36	IT industry employment	C84	96465	61821	42706	109453	68277
37	Registered urban unemployment	C85	82067	111071	106709	89022	80963
38	Average wage of employees	C91	46	43	32	49	63
39	PM2.5	C92	630	774	571	457	529
40	Urban construction land area	C93	39.23	45.1	40.63	43.37	40.83

Table 3. *Continued.*

No.	Secondary index	Serial number	Wuhan	Changsha	Chengdu	Kunming	Xi'an
1	Total population	C01	884	729	1476	572	987
2	Population growth rate	C02	8.09	7.52	3.64	8.88	10.98
3	Number of R&D staff	C03	86000	96345	143289	65778	101500
4	Number of cell phone users	C04	1684	1251	2867	1229	1858
5	Number of Internet broadband access subscribers	C05	493	328	679	249	393
6	Foreign direct investment contract projects	C11	250	329	494	111	219
7	Actual amount of foreign capital used in the year	C12	1092684	77997	1227500	85013	635370
8	Number of industrial enterprises above the scale	C13	2651	2934	3438	1015	1385
9	Total profit of enterprises above the scale	C14	7334000	7939200	5200081	1498546	3455000
10	Total retail sales of social consumer goods	C21	68439017	47650415	68018100	27874053	46587164
11	Number of wholesale and retail trade enterprises	C22	2249	2085	1599	813	1292
12	Imports of goods	C23	8732000	4601922	22362832	6169230	13460734
13	Proportion of tertiary industry	C24	54.61	54.75	54.12	56.59	61.86
14	Number of general higher education schools	C31	84	51	57	51	63
15	Number of full-time teachers in general higher education institutions	C32	58586	35441	49448	29496	49018
16	Number of general undergraduate and college students	C33	969323	703519	840297	547277	712810
17	Education Expenditure	C34	2599758	1946010	2658194	1300493	1571932
18	Total investment in municipal construction	C41	11060046	661678	9206995	2155557	7730000
19	Sales area of commercial properties	C42	2184	2387	3682	1910	2713
20	Local general public budget revenue	C43	15286984	8797072	14241550	5956333	6847035
21	Social electricity consumption	C44	5803372	3636932	6374116	3374433	3967465
22	Total annual bus passenger traffic	C51	145246	68457	161946	77240	135919
23	Number of actual cabs at the end of the year	C52	17885	7840	14964	8037	14212
24	Road, water and air passenger volume	C53	10419	7085	14729	9155	20020
25	Road, water and air freight volume	C54	237108	121197	693207	458960	338330
26	Gross regional product (current year prices)	C61	148472900	110034116	153427716	52068979	83498600
27	GDP per capita	C62	135136	136920	94782	76387	85114
28	GDP growth rate	C63	8.09	8.52	8.0	8.4	8.2
29	Science and technology expenditures	C71	1344072	361871	730705	180075	482295
30	R&DInternal expenditure	C72	3784174	2658635	3923101	1123800	4261400
31	R&D internal expenditure	C73	60511	41034	107801	23921	56408
32	Patent Applications	C74	8807	4823	8304	1807	8023
33	Patents granted for inventions	C81	2097735	1194467	6135401	1336684	1962340
34	Number of employees in urban units	C82	2461100	2347700	3054922	2296869	2020051

No.	Secondary index	Serial number	Wuhan	Changsha	Chengdu	Kunming	Xi'an
35	Number of urban self-employed and private employees	C83	95381	22319	331444	25305	101678
36	IT industry employment	C84	81900	36877	204718	62380	124803
37	Registered urban unemployment	C85	88327	93293	88011	80253	87125
38	Average wage of employees	C91	49	48	51	28	61
39	PM2.5	C92	865	505	848	454	658
40	Urban construction land area	C93	39.46	41.49	41.33	41.93	38.75

4.2. Data Processing

The above data was handled using SPSS 20.0 software in the following steps.

Step 1: Transposition of data. Transpose Table 3 with rows and columns of data for the purpose of data analysis.

Step 2: Positiveization of the inverse indicator. PM2.5, the 38th indicator out of the above 40 indicators, is the inverse indicator, and it is made explicit by finding the inverse.

Step 3: Normalization of data. Normalization of the data processed in step 1 to get a table of standardized values.

Step 4: Using the standard values obtained in step 3, the objective weight values determined by the CRITIC method, the entropy weight method and the information quantity method are calculated for each indicator, and the average value determined by the three objective methods is used as the comprehensive objective weight of each indicator, as shown in Table 4.

Table 4. *Indicator weight table.*

No	Secondary Indicator	CRITIC weights	Entropy method	Information weight	Combined objective weights
1	Total population	0.0202	0.0230	0.0272	0.0235
2	Population growth rate	0.0365	0.0125	0.0162	0.0217
3	Number of R&D staff	0.0191	0.0176	0.0207	0.0191
4	Number of cell phone users	0.0187	0.0249	0.0275	0.0237
5	Number of Internet broadband access subscribers	0.0154	0.0235	0.0239	0.0209
6	Foreign direct investment contract projects	0.0230	0.0324	0.0299	0.0284
7	Actual amount of foreign capital used in the year	0.0204	0.0318	0.0285	0.0269
8	Number of industrial enterprises above the scale	0.0200	0.0221	0.0243	0.0221
9	Total profit of enterprises above the scale	0.0258	0.0214	0.0224	0.0232
10	Total retail sales of social consumer goods	0.0193	0.0198	0.0208	0.0200
11	Number of wholesale and retail trade enterprises	0.0223	0.0228	0.0258	0.0236
12	Import of goods	0.0205	0.0251	0.0247	0.0234
13	Proportion of tertiary industry	0.0302	0.0154	0.0190	0.0215
14	Number of general higher education schools	0.0270	0.0190	0.0231	0.0230
15	Number of full-time teachers in general higher education institutions	0.0278	0.0300	0.0259	0.0279
16	Number of general undergraduate and college students	0.0304	0.0217	0.0222	0.0248
17	Education Expenses	0.0179	0.0207	0.0218	0.0201
18	Total investment in municipal construction	0.0259	0.0284	0.0272	0.0272
19	Sales area of commercial properties	0.0346	0.0294	0.0276	0.0305
20	Local general public budget revenue	0.0202	0.0285	0.0264	0.0250
21	Social electricity consumption	0.0195	0.0365	0.0301	0.0287
22	Total annual bus passenger traffic	0.0235	0.0200	0.0215	0.0217
23	Number of actual cabs at the end of the year	0.0313	0.0231	0.0223	0.0256
24	Road, water and air passenger volume	0.0320	0.0267	0.0274	0.0287
25	Road, water and air freight volume	0.0288	0.0281	0.0267	0.0279
26	Gross regional product (current year prices)	0.0187	0.0187	0.0203	0.0192
27	GDP per capita	0.0301	0.0286	0.0259	0.0282
28	GDP growth rate	0.0361	0.0094	0.0125	0.0193
29	Science and technology expenditures	0.0248	0.0287	0.0261	0.0265
30	R&D internal expenditure	0.0207	0.0175	0.0194	0.0192
31	Patent Applications	0.0200	0.0234	0.0224	0.0219
32	Patents granted for inventions	0.0215	0.0163	0.0183	0.0187
33	Number of employees in urban units	0.0190	0.0438	0.0408	0.0345
34	Number of urban self-employed and private employees	0.0232	0.0249	0.0270	0.0250
35	IT industry employment	0.0181	0.0432	0.0361	0.0325
36	Registered urban unemployment	0.0283	0.0281	0.0288	0.0284
37	Average wage of employees	0.0272	0.0327	0.0304	0.0301
38	PM2.5	0.0411	0.0281	0.0285	0.0326
39	Urban construction land area	0.0250	0.0296	0.0267	0.0271
40	Greening coverage of built-up areas	0.0357	0.0225	0.0239	0.0274

Step 5: Based on the weights of each indicator calculated in step 4 and the standard values obtained in step 3, the total score of the urban entrepreneurial ecosystem is calculated with (1).

$$C_{\mathrm{i}} = \sum_{j=1}^{n} \mathrm{w}_{ij} \times \mathrm{d}_{ij}, i = 1,2...,10 \quad (1)$$

In (1), C_{i} is the composite score of entrepreneurial activity of the ith city, W_{ij} is the weight value of the ith city and the jth indicator, and d_{ij} is the standardized value of the ith city and the jth indicator. The scores of each city on the secondary indicators calculated by (1) are shown in Table 5.

Table 5. *Score of secondary indicators by city.*

Dimension	Tier 1 Indicators	Secondary indicators	Shenyang	Nanjing	Hangzhou	Hefei	Zhegnzhou
Synergy	Population	Total population	0.0045	0.0032	0.0052	0.0048	0.0076
		Natural growth rate	0.0000	0.0080	0.0101	0.0217	0.0167
		Number of R&D staff	0.0000	0.0162	0.0083	0.0068	0.0053
		Number of cell phone users	0.0040	0.0035	0.0101	0.0000	0.0075
	Enterprise	Number of Internet broadband access subscribers	0.0000	0.0102	0.0129	0.0037	0.0091
		Foreign direct investment contract projects	0.0034	0.0234	0.0284	0.0025	0.0000
		Actual amount of foreign capital used in the year	0.0015	0.0072	0.0141	0.0057	0.0080
		Number of industrial enterprises above the scale	0.0022	0.0077	0.0221	0.0064	0.0084
		Total profit of enterprises above the scale	0.0044	0.0219	0.0232	0.0027	0.0089
	Demand	Total retail sales of social consumer goods	0.0062	0.0150	0.0144	0.0009	0.0073
		Number of wholesale and retail trade enterprises	0.0051	0.0147	0.0236	0.0035	0.0073
		Imports of goods	0.0024	0.0179	0.0180	0.0048	0.0141
		The proportion of tertiary industry	0.0124	0.0170	0.0215	0.0000	0.0069
Emerge	Education	Number of general higher education schools	0.0037	0.0068	0.0000	0.0052	0.0110
		Number of full-time teachers in general higher education institutions	0.0000	0.0220	0.0032	0.0004	0.0214
		Number of general undergraduate and college students	0.0000	0.0138	0.0017	0.0044	0.0248
		Education Expenses	0.0000	0.0139	0.0201	0.0049	0.0098
	Municipalities	Total investment in municipal construction	0.0062	0.0018	0.0107	0.0027	0.0114
		Sales area of commercial properties	0.0016	0.0000	0.0056	0.0021	0.0305
		Local general public budget revenue	0.0025	0.0178	0.0250	0.0024	0.0113
		Social electricity consumption	0.0012	0.0168	0.0287	0.0005	0.0139
	Traffic	Total annual bus passenger traffic	0.0111	0.0068	0.0200	0.0000	0.0078
		Number of actual cabs at the end of the year	0.0247	0.0140	0.0150	0.0040	0.0078
		Passenger volumes by road, water and air	0.0179	0.0055	0.0109	0.0021	0.0044
		Fright volumes by road, water and air	0.0021	0.0024	0.0269	0.0000	0.0130
	Economy	Gross regional product (current year prices)	0.0021	0.0144	0.0158	0.0050	0.0094
		GDP per capita	0.0000	0.0282	0.0236	0.0079	0.0094
		GDP growth rate	0.0000	0.0160	0.0081	0.0193	0.0179
Phase change	Technology Innovation	Science and technology expenditures	0.0000	0.0143	0.0228	0.0169	0.0041
		R&D internal expenditure	0.0000	0.0166	0.0192	0.0079	0.0040
		Patent Applications	0.0000	0.0196	0.0195	0.0110	0.0121
		Number of Invention Patents Granted	0.0023	0.0187	0.0170	0.0076	0.0178
	Employment	Number of employees in urban units	0.0000	0.0070	0.0112	0.0045	0.0049
		Number of urban self-employed and private employees	0.0039	0.0250	0.0215	0.0000	0.0046
		IT industry employment	0.0002	0.0173	0.0145	0.0028	0.0032
		Registered Urban Unemployment	0.0101	0.0042	0.0010	0.0123	0.0053
		Average wage of employees	0.0018	0.0301	0.0258	0.0086	0.0007
	Environment	PM2.5	0.0096	0.0121	0.0252	0.0074	0.0000
		Urban construction land area	0.0116	0.0211	0.0077	0.0002	0.0049
		Greening coverage of built-up areas	0.0021	0.0274	0.0081	0.0199	0.0090

Table 5. *Continued.*

Dimension	Tier 1 Indicators	Secondary indicators	Wuhan	Changsha	Chengdu	Kunming	Xi'an
Synergy	Population	Total population	0.0081	0.0041	0.0235	0.0000	0.0108
		Natural growth rate	0.0117	0.0110	0.0057	0.0128	0.0157
		Number of R&D staff	0.0068	0.0091	0.0191	0.0025	0.0102
		Number of cell phone users	0.0086	0.0031	0.0237	0.0028	0.0108
	Enterprise	Number of Internet broadband access subscribers	0.0121	0.0043	0.0209	0.0005	0.0074
		Foreign direct investment contract projects	0.0072	0.0106	0.0177	0.0012	0.0059
		Actual amount of foreign capital used in the year	0.0237	0.0000	0.0269	0.0002	0.0130
		Number of industrial enterprises above the scale	0.0082	0.0096	0.0121	0.0000	0.0019
		Total profit of enterprises above the scale	0.0172	0.0189	0.0109	0.0000	0.0058
	Demand	Total retail sales of social consumer goods	0.0200	0.0097	0.0198	0.0000	0.0092
		Number of wholesale and retail trade enterprises	0.0093	0.0082	0.0051	0.0000	0.0031
		Imports of goods	0.0054	0.0000	0.0234	0.0021	0.0117
		The proportion of tertiary industry	0.0068	0.0071	0.0061	0.0100	0.0183
Emerge	Education	Number of general higher education schools	0.0230	0.0058	0.0089	0.0058	0.0120

Dimension	Tier 1 Indicators	Secondary indicators	Wuhan	Changsha	Chengdu	Kunming	Xi'an
		Number of full-time teachers in general higher education institutions	0.0279	0.0077	0.0199	0.0026	0.0196
		Number of general undergraduate and college students	0.0238	0.0128	0.0185	0.0064	0.0132
		Education Expenses	0.0146	0.0080	0.0151	0.0015	0.0042
		Total investment in municipal construction	0.0272	0.0000	0.0223	0.0039	0.0185
	Municipalities	Sales area of commercial properties	0.0118	0.0143	0.0302	0.0084	0.0183
		Local general public budget revenue	0.0190	0.0058	0.0169	0.0000	0.0018
		Social electricity consumption	0.0152	0.0016	0.0187	0.0000	0.0037
		Total annual bus passenger traffic	0.0183	0.0026	0.0217	0.0044	0.0164
	Traffic	Number of actual cabs at the end of the year	0.0256	0.0000	0.0181	0.0005	0.0162
		Passenger volumes by road, water and air	0.0074	0.0000	0.0170	0.0046	0.0287
		Fright volumes by road, water and air	0.0086	0.0037	0.0279	0.0180	0.0129
		Gross regional product (current year prices)	0.0183	0.0110	0.0192	0.0000	0.0060
	Economy	GDP per capita	0.0217	0.0224	0.0070	0.0002	0.0034
		GDP growth rate	0.0166	0.0192	0.0160	0.0185	0.0172
		Science and technology expenditures	0.0265	0.0041	0.0126	0.0000	0.0069
	Technology	R&D internal expenditure	0.0145	0.0084	0.0153	0.0000	0.0171
	Innovation	Patent Applications	0.0096	0.0045	0.0219	0.0000	0.0085
		Number of Invention Patents Granted	0.0141	0.0061	0.0131	0.0000	0.0125
Phase change		Number of employees in urban units	0.0064	0.0001	0.0345	0.0011	0.0054
		Number of urban self-employed and private employees	0.0074	0.0065	0.0118	0.0062	0.0041
	Employment	IT industry employment	0.0077	0.0000	0.0325	0.0003	0.0083
		Registered Urban Unemployment	0.0076	0.0000	0.0284	0.0043	0.0149
		Average wage of employees	0.0079	0.0127	0.0076	0.0000	0.0067
		PM2.5	0.0074	0.0081	0.0061	0.0326	0.0009
	Environment	Urban construction land area	0.0271	0.0034	0.0260	0.0000	0.0135
		Greening coverage of built-up areas	0.0031	0.0118	0.0111	0.0137	0.0000

The scores and total score of each city on the three major dimensions are shown in Table 6.

Table 6. *Score of each dimension and total score.*

Dimension	Shenyang	Nanjing	Hangzhou	Hefei	Zhengzhou	Wuhan	Changsha	Chengdu	Kunming	Xi'an
Collaboration	0.0462	0.1659	0.2122	0.0635	0.1070	0.1453	0.0957	0.2149	0.0322	0.1237
Emerge	0.0711	0.1215	0.1678	0.0286	0.1671	0.2222	0.0624	0.2352	0.0561	0.1655
Phase-change	0.0437	0.2721	0.2411	0.1313	0.1072	0.1958	0.1183	0.2630	0.0769	0.1255
Total score	0.1610	0.5595	0.6211	0.2234	0.3813	0.5633	0.2764	0.7131	0.1652	0.4146

4.3. Analysis Results

The scores of the 10 quasi-first-tier cities on each dimension and total score are shown in Figure 1. In terms of total score, Chengdu, Hangzhou, Wuhan and Nanjing are in the top 4, with relatively few gaps, and are in the first tier; Xi'an, Zhengzhou and Changsha are in the second tier at 5-7; while Hefei, Kunming and Shenyang have lower scores and are in the third tier.

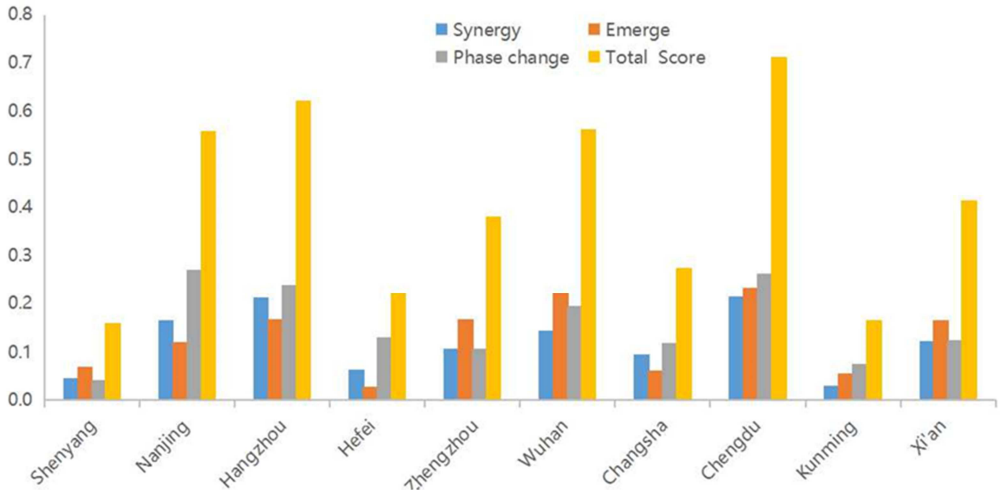

Figure 1. *City dimensions and total scores.*

As was shown in Figure 2, in the synergy dimension, Chengdu, Hangzhou and Nanjing ranked in the top three. In the emergence dimension, Chengdu, Wuhan and Hangzhou ranked in the top three. In the phase change dimension, Nanjing, Chengdu and Hangzhou ranked in the top three. It is worth nothing that the cities with the highest overall scores have a more balanced score in all three dimensions. For example, Chengdu ranked first in the synergy and emergence dimensions and second in the phase change dimension, with a clear overall advantage and greater potential. Nanjing ranked first in the phase change dimension because it ranked first in the economy, technological innovation, employment and environment indicators, and ranked second after Hangzhou in technological innovation and Chengdu in employment. For example, Hefei's scores in the emergence dimension and the phase change dimension are several times different. While Kunming and Shenyang's scores in all three dimensions are at a lower level and the difference in score is obvious.

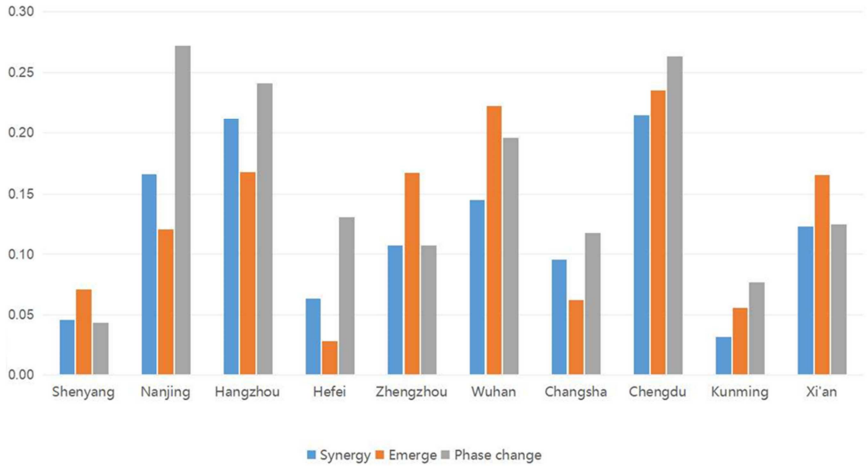

Figure 2. *Map of three dimensional scores by city.*

The radar chart of secondary indicators for each city is shown in Figure 3. It can be seen that the cities with leading overall scores all have 1-2 indicators with obvious leading advantages, such as employment indicators in Chengdu, education indicators in Wuhan, enterprise indicators in Hangzhou and environmental indicators in Nanjing. The results of the measurement analysis are revealing.

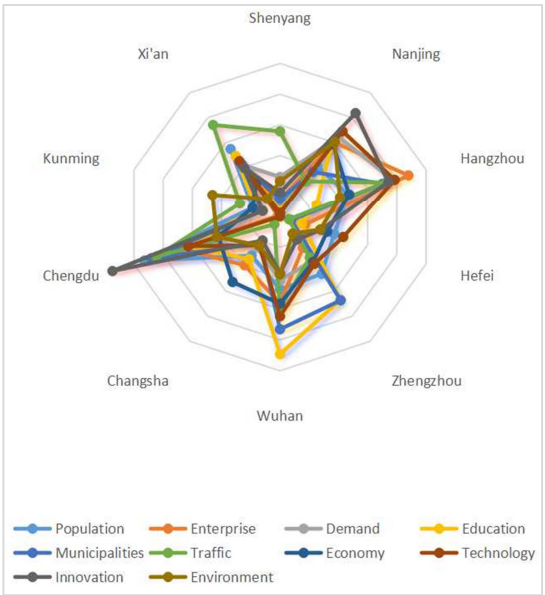

Figure 3. *Radar map of secondary indicators by city.*

(1) The quality of urban entrepreneurial ecosystems is determined by a multidimensional combination of factors, among which employment, technological innovation, natural environment, municipalities, transportation and education have become key ordinary covariance. And a particularly strong performance on one of the sequential key covariance is a common characteristic of cities with leading overall scores, such as Chengdu and Nanjing.

(2) Employment has always been the basis of livelihoods, both as the main goal to be achieved by entrepreneurial activity and as a core indicator of the quality of urban entrepreneurial ecosystems.

(3) Technological innovation significantly affects the quality of urban entrepreneurial ecosystems, with the leading first-tier cities scoring higher on technological innovation indicators.

(4) Both the hard and soft environments have a positive impact on entrepreneurial activities. In the context of the public's overall emphasis on quality of life, a beautiful environment, municipal cleanliness and convenient transportation have become important considerations for entrepreneurs to choose a place to register with their companies.

(5) The role of knowledge spillover and tacit knowledge dissemination played by education has a greater impact on the entrepreneurial climate of a city, especially the level of teaching and research of faculty and students in higher education institutions, as the main source of entrepreneurs, determines the development potential of a city's entrepreneurial ecosystem.

5. Conclusion

As a typical social system, the complexity of entrepreneurial activity is obvious, and the ultimate goal of its study and measurement is to promote economic development for sustainable livelihood improvement. As an emerging field in entrepreneurship research, the entrepreneurial ecosystem is not only a biological metaphor, but also reveals that the complexity of entrepreneurial activities is rooted in the non-linear interactions among the participating actors. An internal and external study of city-level entrepreneurial ecosystems shows that the relationship between firms and government, as the main participants in entrepreneurial activities, has a significant impact on the type and growth of regional entrepreneurial firms; the natural, cultural and institutional environments of cities determine and sustainably influence regional entrepreneurship.

During the evolution of the entrepreneurial ecosystem, three major characteristics of synergy, emergence and phase change will appear one after another. First, the entrepreneur's personal initiative will greatly influence the establishment of the system's relationship network, thus forming a synergistic evolutionary situation in which all subjects in the entrepreneurial system rely on each other and influence each other; second, each subject forms an objective self-organizing behavior while seeking their own interests, which makes the overall effectiveness of the entrepreneurial ecosystem greater than the simple superposition of the effectiveness of each subject, and this emergent effect is the greatest value of the entrepreneurial ecosystem and the fundamental reason why entrepreneurial activities can drive economic development; finally, through a long period of high-quality development and the establishment of continuous and open interaction with the outside world, the urban entrepreneurial ecosystem will gradually transition from factor-driven to efficiency-driven and finally to innovation-driven, and the transformation and upgrading between these three stages is a process of phase change.

By constructing the Urban Entrepreneurship Ecosystem Index (UEEI) with three dimensions of synergy, emergence and phase change, 10 primary indicators and 40 secondary indicators, this study hopes to integrate many economic and non-economic indicators based on the theory of complexity science, and comprehensively examine the quality of urban entrepreneurial activities from the perspective of complex systems. This study aims to examine the quality of urban entrepreneurial activities from a complex system perspective by integrating many economic and non-economic indicators based on complexity science theory. This study verifies the reasonableness and usefulness of this index system by analyzing 10 quasi-first-tier cities in China. The results show that cities with high quality entrepreneurial ecosystems have balanced performance and high scores in all three dimensions, while cities with low scores have low scores in all dimensions and large differences in scores; among the primary and secondary indicators reflecting the quality of the system, soft environments such as employment, technological innovation and education, and hard environments such as PM2.5, municipalities and transportation are important. These soft and hard environments are key ordinal parameters that determine the overall characteristics of a city's entrepreneurial ecosystem, and particularly good performance on one of the key ordinal parameters is a common characteristic of cities with high overall scores, such as Chengdu, Nanjing and Wuhan.

Creating a sustainable, high-quality urban entrepreneurial ecosystem is not an easy task due to the complexity of the system. For large cities in China, finding their own characteristics and differentiating advantages based on their historical and cultural heritage and economic geography is the key to developing entrepreneurial ecosystems and driving economic development through entrepreneurship. The way to improve the quality of urban entrepreneurial ecosystem is to improve the hardware and software, enhance the efficiency of urban governance, make full use of policy leverage to promote scientific and technological innovation and transformation of technological achievements, encourage high-level technical personnel to engage in entrepreneurial activities, create a positive entrepreneurial culture and social atmosphere, and attract well-known enterprises and entrepreneurs with favorable conditions.

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