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Urban Innovation Ecosystems and Sustainable Development in a Latecomer City: A Case Study in Zhangzhou, China

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Abstract: Building a good innovation ecosystem for latecomer cities in regional integration can help achieve long-term sustainable development. This paper constructs a conceptual framework for urban innovation ecosystems from a life cycle perspective. This paper chose Zhangzhou City as a case to analyze the evolution of urban innovation ecosystems from 2004 to 2022. The study shows that Zhangzhou's innovation ecosystem is growing, and the system is improving steadily. However, the impact of mobility of innovation factors on the innovation ecosystem needs attention. This paper proposes that latecomer cities further improve the governance system related to the innovation ecosystem, construct an open and shared industry-university-research collaboration mechanism, and guide society in the construction of urban innovation ecology. The finding is important for understanding the construction of innovation ecosystems in developing cities.

Keywords: Innovation ecosystem; Sustainable development; Latecomer city; Case study

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1. Introduction

Innovation capability is an important cornerstone for promoting the sustainable development of the urban economy. For cities, the enhancement of comprehensive innovation capability depends on the construction of a good innovation ecosystem. The innovation ecosystem is the interaction between innovation subjects (enterprises, scientific research institutions, government, etc.), elements, and the environment, forming a sustainable complex ecosystem [1]. Research shows that by promoting knowledge creation, technology transfer, and enterprise innovation, an innovation ecosystem helps enhance regional innovation capability, industrial chain resilience, and the promotion of low-carbon economic development [2–4].

The concept of a regional innovation ecosystem originates from the expansion of innovation system theory, which emphasizes innovation activities' social and technical network characteristics [5–6]. At present, relevant research on innovation ecosystems has discussed the interaction and synergistic development among innovation subjects, innovation elements, and the innovation environment within the system and stressed that the government plays a key role in the regional innovation ecosystem by providing policy support, capital input, and an institutional environment to promote the development of the innovation ecology system [7]. The policy design of a regional innovation ecosystem needs to consider the region's specific conditions and the ecosystem's intrinsic needs to achieve policy effectiveness and adaptability [8].

For the dynamic analysis of the urban innovation ecosystem, the spatiotemporal location of a city needs to be considered. First, each city is in a different "life cycle" in time. Owing to different historical development statuses, geographic locations, and policy influences, the speed of urban development varies. Some cities are in the prime of gradual development. Meantime, other cities face the problem of "contraction" during recessions [9]. On the other hand, a city's economy is spatially affected by the economic development status of the region in which it is located. Against the background of existing policies, local development within a province is rising in a spiral, accompanied by national policy in the two-way transformation of "coordinative regional development" and "key development of central cities" to achieve sustainable development as much as possible "with limited resources" and compete for various factor flows (likes capital flow, talent flow) between and within regions [10]. This means that once the "spillover effect" of the core cities in the region is lower than the "siphon effect", the gap between the "core-border" cities in the region will widen. Border cities are prone to weakening with the rise of core cities, while core cities will gradually weaken. Cities create development bottlenecks due to space limitations and public service provision [11–12]. Therefore, this case study will be helpful for further understanding the spatiotemporal evolution of the innovation ecosystem.

In this paper, Zhangzhou City was selected as the research object. On the one hand, Zhangzhou was a latecomer in the regional integration of Xiamen, Zhangzhou, and Quanzhou. In the past 20 years, it has transformed from an agriculture-based economy to an industry-oriented economy, and its economic growth has lagged behind Xiamen, a special economic zone, and Quanzhou, with a developed private economy. On the other hand, Zhangzhou has enjoyed good development momentum in recent years, and the government has been actively promoting various urban innovation policies. The case of Zhangzhou will help us understand the choices of innovative development strategies of latecomer cities against the background of regional policies; this is of particular importance in theory and policy.

The paper is organized as follows: Section 2 discusses the conceptual framework. Section 3 presents the research design and describes the methods. Section 4 presents the case analysis, and Section 5 presents the conclusions and future directions for further research.

2. Framework of urban innovation ecosystems from the life cycle

The urban innovation ecosystem includes four components: innovation subjects, innovation activities, innovation outputs, and the institutional environment [13]. Innovation subjects refer to different types of players, including enterprises, research institutions, universities, governments, and individuals. Innovation activity is a series of innovation-related behaviors involving R&D, production, and trade. Innovation outputs include products, services, technologies, and knowledge resources. The institutional environment includes city laws and policies, and informal institutions such as culture and norms.

As shown in **Figure 1**, from the life cycle perspective, evolution analysis reveals that an urban innovation ecosystem will undergo the following stages: the early stage (germination stage), growth stage, maturity stage, or decline stage, and innovation subjects, activities, outputs, and institutional environments differ [14–15].

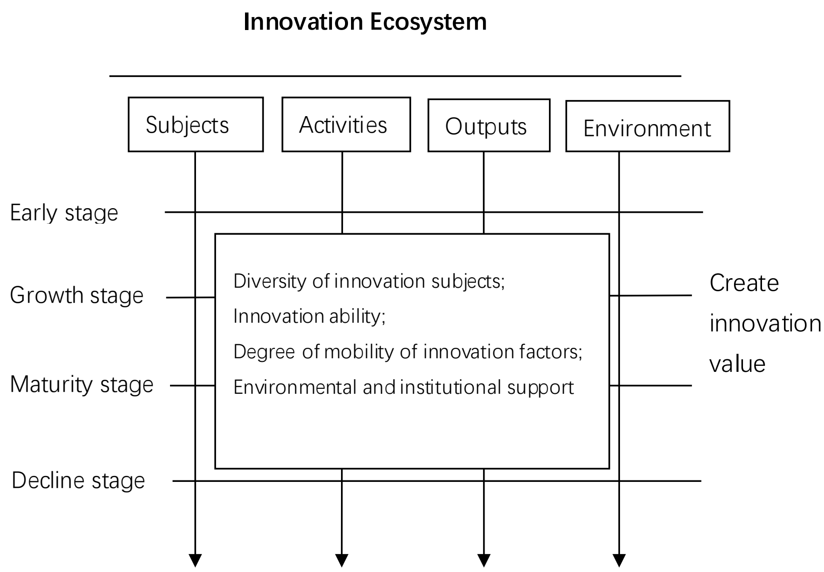

Figure 1. The evolution path of the urban innovation ecosystem

In the early stage, the number of innovation entities in the innovation ecosystem was relatively small, and the lack of interaction mechanisms further limited the number of innovation activities and outputs [16]. Compared with formal institutions, informal institutions play a more significant role in the early stage, and regions with an adventurous spirit and risk preference engage in relatively more innovative activities. According to the analysis of resilience characteristics, the innovation ecosystem is relatively fragile because there are few participants, the flow of resources and information is limited, and there is a lack of sufficient resources and capabilities to absorb and mitigate external shocks. Effective learning and adaptation mechanisms have not yet been formed.

During the growth stage, with the accumulation of resources and the expansion of the network, new entrants begin to increase, the mobility of the innovation ecosystem increases significantly, and capital, talent, information, and technology begin to flow more frequently. Formal institutional arrangements conducive to leading innovation activities are critical at this stage. A sound institutional environment leads to a rapid increase in innovation output, which manifests as a continuous increase in buffering and evolution, thereby significantly improving the resilience of the innovation ecosystem [17]. Conversely, due to internal imbalance or external black swan events, the innovation ecosystem can enter a negative cycle and be unable to further develop into the maturity stage or even decline.

An innovation ecosystem that has entered the mature stage has complex and diverse innovation subjects, efficient and systematic innovation activities, a relatively complete policy support system, industry norms, cultural identity, and the strength of innovation output radiating outward. The resilience of the innovation ecosystem reaches a maximum, which can effectively absorb shocks and maintain system stability. However, an innovation ecosystem at the mature stage may still decline under external or internal shocks. During recessions, the resilience of the innovation ecosystem is relatively fragile, and the system cannot effectively resist and recover from exogenous shocks.

The dimensional characteristics of innovation ecosystem resilience differ across different periods, and the differences in the innovation ecosystems of different cities lead to different development paths of cities in the face of a shock. From the life cycle perspective, a resilient innovation ecosystem has diverse innovation subjects, efficient mobility of innovation factors, and sufficient environmental and institutional support, thus exhibiting high innovation capability. Such a system can promote the generation and application of knowledge, maintain competitiveness through interactions between subjects, quickly adapt to environmental changes, and effectively respond to the evolution of the market and technology. It can also recover quickly after a shock, breaking the original path dependence and improving the overall performance of the innovation ecosystem.

In the following section, the evaluation system is constructed from the four aspects of the diversity of innovation subjects, the degree of mobility of innovation factors, the environmental and institutional support, and the innovation ability. In detail, the study analyzed the Zhangzhou innovation ecosystem from 2004 to 2022 and its characteristics and imbalance level.

3. Cases and research methods

3.1. Case introduction

Zhangzhou city is located in southeastern Fujian Province and governs four districts, seven counties, and five development zones. In higher-level planning, various policies have strongly promoted Xiamen–Zhangzhou–Quanzhou regional integration. The "Golden Triangle of Southern Fujian" is formed by Xiamen and Quanzhou cities. Urban agglomeration is a common feature of southern Fujian culture and geographic proximity. Regarding infrastructure, the integration of communication between cities and the connection of intercity high-speed railways and bus card swipes have been realized. In addition, the joint protection of water basins and cooperation in controlling environmental pollution have been carried out [18]. As mentioned earlier, Zhangzhou's economic development is relatively weak within the urban agglomeration (**Figure 2**), and it was a latecomer in the urban agglomeration. The unbalanced development among regions may cause more resources to flow out of Zhangzhou in urbanization [19]. In addition, the development of the districts and counties within Zhangzhou is relatively uneven, and the economic policies are biased toward promoting the development of the central urban area (Longwen, Xiangcheng, Longhai, Changtai) and the four major development zones. The central city core area is an urbanization area promoted mainly by Zhangzhou city and the frontier of urbanization with Xiamen, with a relatively high level of economic development.

In contrast, other counties and districts are biased toward traditional agriculture and the cultural and tourism industry. To catch up with the development of its surrounding cities, Zhangzhou's planning in recent years has focused on the differentiated development of characteristic regional industries, emerging manufacturing industries, and biomedicine and health industries. More significant policy support has also been given regarding talent introduction policies, subsidies for high-tech enterprises, and the construction of entrepreneurial incubation platforms. In terms of higher education resources, Zhangzhou currently has an undergraduate university and a branch campus of a key university, and these two schools are the leading players in promoting the establishment of a regional industry-university-research alliance. Therefore, with accelerating economic growth and policy support, is the quality of Zhangzhou's innovation ecosystem steadily improving? This is what the authors want to explore further.

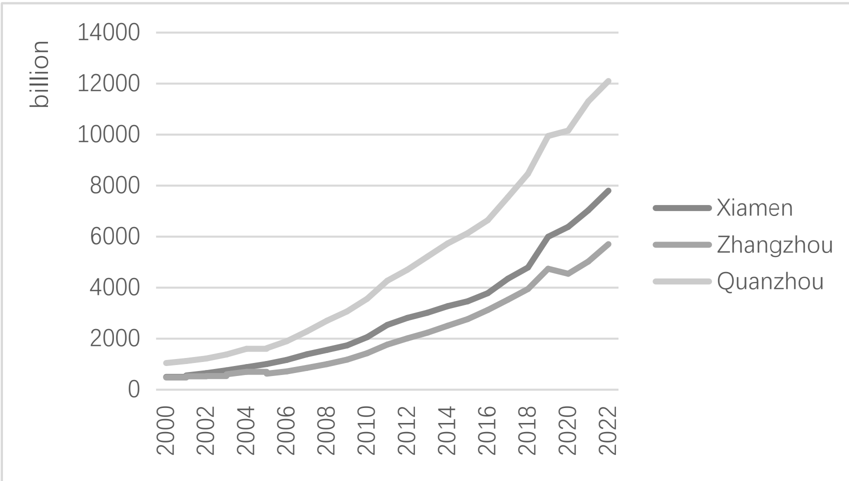

Figure 2. Xiamen, Zhangzhou, and Quanzhou's GDP from 2000 to 2022

3.2. Calculation steps: Measurement methods

This paper uses the distance method between superior and inferior solutions modified by the entropy weight method (entropy weight TOPSIS method) for measurement. In the measurement process, each reference indicator was first standardized to avoid differences caused by different units of each indicator. On this basis, the entropy weight method was used to assign the weight of each indicator objectively, and the TOPSIS method was finally used for ranking to ensure the authenticity and validity of the research data as much as possible. The specific operation steps of the above methods are as follows:

3.2.1. Data standardization

The indicators are divided into positive indicators and negative indicators. The positive indicators are the indicators whose larger values are better. The opposite is true for the negative indicators. The original data needs to be standardized to eliminate the differences in the dimension and order of magnitude of different indicators.

Positive indicators: $x'_{ij} = \frac{x_{ij} - min(x_{1j}, x_{2j}, \ldots\ldots x_{nj})}{max(x_{1j}, x_{2j}, \ldots\ldots x_{nj}) - min(x_{1j}, x_{2j}, \ldots\ldots x_{nj})}$ (Formula 1)

Converse indicator: $x'_{ij} = \frac{max(x_{1j}, x_{2j}, \ldots\ldots x_{nj}) - x_{ij}}{max(x_{1j}, x_{2j}, \ldots\ldots x_{nj}) - min(x_{1j}, x_{2j}, \ldots\ldots x_{nj})}$ (Formula 2)

where i represents the year and j represents the j-th indicator in the indicator system. x'_{ij} refers to the normalized value.

3.2.2. Proportion of standardized values

The proportion of the normalized value of the city's score under each indicator was calculated as P_{ij}, indicating the contribution level of different samples under different indicators.

$P_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}}$ $(0 < P_{ij} < 1)$ (Formula 3)

where m represents the year.

(3) Calculate the information entropy and information utility values of the indicators

The information entropy formula for the j-th indicator is:

$$e_j = -\frac{\sum_{i=1}^{m} p_{ij} \ln p_{ij}}{\ln n} \quad \text{(Formula 4)}$$

where n is a constant and where n is the number of indicators.

The information utility value d_j depends on the index information entropy e_j.

$$d_j = 1 - e_j \quad \text{(Formula 5)}$$

The larger the information entropy is, the smaller the information utility value, and the smaller the weight.

(4) Calculate the indicator weights

The weight of an indicator is determined by the degree of contribution to the entire evaluation system; therefore, the formula for the weight is as follows:

$$w_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \quad \text{(Formula 6)}$$

(5) Calculate the optimal distance

Construct a weighting matrix of the measure indicators and calculate the optimal level Q_i^+ and worst level Q_i^-:

$$Q = (q_{ij})_{m*n} \quad \text{(Formula 7)}$$

of which $q_{ij} = W_j * Y_{ij}$.

Then, calculate the Euclidean distance between each evaluation object and the optimal level and the worst level. The specific calculation formula is as follows:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} (q_{ij} - Q_j^+)^2} \quad \text{(Formula 8)}$$

3.2.3. Construction of innovation ecosystem indicators

In this study, considering the principles of data scientificity, representativeness, and availability, the authors select 19 secondary indicators that could reflect Zhangzhou city's characteristics from the four dimensions of the diversity of innovation subjects, degree of mobility of innovation factors, environmental and institutional support, and innovation ability. These indicators represent the status of the innovation ecosystem.

The diversity of innovation subjects is divided into enterprise diversity, university diversity, and industrial diversity. The quantity and quality of innovation subjects from enterprises and universities should be considered. The degree of mobility of innovation factors includes three aspects: capital flow, goods flow, and labor mobility. Knowledge and technology flows are not included because they are difficult to measure. Considering that Zhangzhou is a coastal port city, the water-borne freight volume is selected as one of the measurement indicators. In terms of environmental and institutional support, from the resource dimension, in addition to the accumulation of economic resources required for innovation activities, natural and social resources are added, of which industrial sulfur dioxide emissions are a negative indicator. Innovation ability starts from innovation activities and selects representative indicators to measure innovation input and output. **Table 1** lists the specific indicators and weights.

Table 1. Index system of the Zhangzhou innovation ecosystem

Dimension	Weight	Primary indicators	Secondary indicators	Weight
Diversity of innovation subjects	0.1956	Enterprise diversity	Quantity of R&D by enterprises above the designated size	0.0791
		College Diversity	Number of students in colleges and universities	0.0236
			Number of full-time teachers in institutions of higher learning	0.0304
		Industrial diversity	Diversity of industrial structure	0.0625
Innovation ability	0.2297	Innovation input	R&D internal expenditures	0.0488
			Science expenditures in the government budget	0.0418
		Innovation outputs	Number of domestic patents granted	0.0830
			R&D personnel of enterprises above the designated size	0.0560
Degree of mobility of innovation factors	0.2319	Fund flow	Import and export trade amount	0.0415
			Per capita actual use of foreign capital in the current year	0.0423
		Goods flow	Road freight volume	0.0566
			Waterborne freight volume	0.0707
		Labor Mobility	Number of employees	0.0207
Environmental and institutional support	0.3429	Policy support	Financial investment in education	0.0527
		Natural environmental	Industrial sulfur dioxide emission	0.0280
		Social and environmental resources	Number of books in public libraries	0.0875
			Number of beds in medical and health institutions	0.0594
		Economic resources	GDP per capita	0.0533
			Per capita balance of deposits in financial institutions at the end of the year	0.0619

4. Evaluation and analysis of the Zhangzhou innovation ecosystem

4.1. Measurement results

The relevant data used in this paper are the "Zhangzhou Statistical Yearbook", "China City Statistical Yearbook", "Zhangzhou Statistical Bulletin on National Economic and Social Development", and the Fujian Provincial Bureau of Statistics from 2004 to 2023.

This paper uses the entropy weight TOPSIS method for measurement analysis. **Table 2** lists the overall score results of Zhangzhou's innovation ecosystem from 2004 to 2022. The value will reach a maximum in 2021, reaching 0.64, nearly six times greater than the 0.11 reported in 2004. Zhangzhou's innovation ecosystem has shown good growth over the past ten years.

Figure 3 visually reflects the variation range of Zhangzhou's innovation system from 2004 to 2022. From 2004 to 2007, the value was relatively low and did not increase significantly. From 2008 to 2016, the value exhibited two precise growth intervals. Since 2017, the value has shown a slight increase in the range and stable fluctuations. Even after the outbreak of the epidemic in 2020, there was no significant decline. Preliminary judgment shows that Zhangzhou's innovation ecosystem entered the growth stage in 2008, which has continued.

Table 2. Zhangzhou innovation ecosystem evaluation scores

Year	Numerical value	Ranking
2004	0.11	16
2005	0.10	18
2006	0.10	19
2007	0.11	17
2008	0.17	15
2009	0.19	14
2010	0.26	13
2011	0.30	12
2012	0.33	11
2013	0.47	10
2014	0.53	9
2015	0.57	7
2016	0.60	5
2017	0.54	8
2018	0.57	6
2019	0.60	4
2020	0.62	3
2021	0.64	1
2022	0.63	2

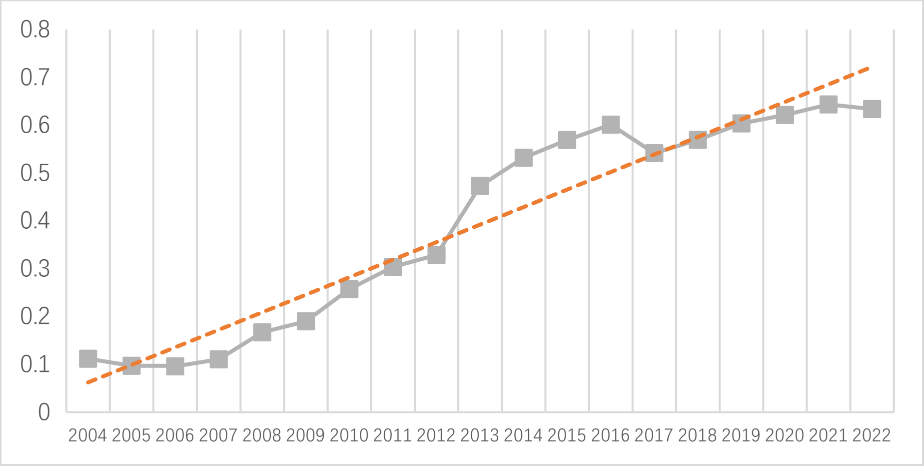

Figure 3. Changes in Zhangzhou's innovation ecosystem from 2004 to 2022

4.2. Dimension analysis

This paper conducts an in-depth analysis of four dimensions to further analyze the innovation ecosystem's status: the diversity of innovation subjects, the degree of mobility of innovation factors, environmental and institutional support, and innovation capability.

4.2.1. Diversity of innovation subjects

As shown in **Table 3**, the diversity of Zhangzhou's innovation ecosystem increased steadily from 2004 to 2022, reached a maximum in 2020, and then declined slightly. After the richness of species and the evenness of individual distributions were considered, the Shannon-Weiner index, commonly used in ecology, was used to measure the diversity characteristics of the subjects. The specific formula is as follows:

$$H = -\sum(p_i * \ln(p_i)) \quad \text{(Formula 9)}$$

P_i represents the proportion of a particular species in the total amount, and H is the index value.

Table 3. Diversity of Zhangzhou's innovation ecosystem

Year	Diversity	Ranking
2004	0.06	17
2005	0.04	19
2006	0.06	18
2007	0.09	16
2008	0.13	15
2009	0.16	14
2010	0.18	13
2011	0.19	12
2012	0.21	11
2013	0.30	10
2014	0.36	9
2015	0.39	8
2016	0.47	7
2017	0.53	6
2018	0.64	5
2019	0.88	2
2020	0.93	1
2021	0.82	4
2022	0.84	3

As shown in **Table 4**, the Shannon index of Zhangzhou's innovation ecosystem remained between 0.17 and 0.21 from 2004 to 2022, which is a relatively stable state. There was no significant increase or decrease in diversity. That is, the number of species in Zhangzhou in enterprises, universities, and industries was a steady increase of the same magnitude; therefore, there was no significant change in the numerical values.

Table 4. Results of the Shannon-Wiener index

Year	Shannon Weiner
2004	0.21
2005	0.20
2006	0.18
2007	0.17
2008	0.17
2009	0.17
2010	0.17
2011	0.17
2012	0.17
2013	0.17
2014	0.18
2015	0.18
2016	0.19
2017	0.19
2018	0.20
2019	0.20
2020	0.19
2021	0.19
2022	0.19

4.2.2. Innovation capability

Innovation capability refers to the ability of the innovation ecosystem to accumulate experience and knowledge, obtain innovation outputs, and enhance the system's creativity through the innovation activities of innovation subjects. As shown in **Table 5**, from 2004 to 2022, the contribution of Zhangzhou's innovation ecosystem and the continuous increase in innovation capability indicates that the innovation input-output ratio of Zhangzhou's regional innovation ecosystem is increasing each year and that the allocation of innovation resources and the innovation environment has achieved a certain extent.

Table 5. Innovation capability of Zhangzhou's innovation ecosystem

Year	Innovation ability	Ranking
2004	0.00	19
2005	0.02	18
2006	0.04	17
2007	0.05	16
2008	0.07	15
2009	0.12	14
2010	0.15	13
2011	0.22	12

Table5 (Continued)

Year	Innovation ability	Ranking
2012	0.28	11
2013	0.34	10
2014	0.35	9
2015	0.40	8
2016	0.47	7
2017	0.54	6
2018	0.69	4
2019	0.77	3
2020	0.80	2
2021	0.82	1
2022	0.69	5

4.2.3. Degree of mobility of innovation factors

As shown in **Table 6**, from 2004 to 2022, the degree of factor mobility in Zhangzhou's innovation ecosystem fluctuated significantly. It peaked in 2015, continued to decline, and then returned to the 2010 level after 2019. The main reason may be the decrease in foreign direct investment and foreign trade cargo throughput.

Table 6. Degree of mobility in Zhangzhou's innovation ecosystem

Year	Mobility	Ranking
2004	0.04	19
2005	0.04	18
2006	0.09	17
2007	0.13	16
2008	0.30	15
2009	0.32	14
2010	0.47	8
2011	0.56	6
2012	0.54	7
2013	0.62	5
2014	0.78	2
2015	0.81	1
2016	0.71	3
2017	0.64	4
2018	0.43	9
2019	0.36	13
2020	0.37	12
2021	0.42	10
2022	0.42	11

4.2.4. Environmental and institutional support

Environmental and institutional support are important dimensions for innovation ecosystems to resist external shocks, and a higher score indicates better system buffering. As shown in **Table 7**, between 2004 and 2022, the environmental and institutional support level for Zhangzhou's innovation ecosystem generally shows an increasing trend. **Figure 4** clearly shows that there was a clear upward trend from 2011 to 2016. At this stage, policy support and resource accumulation achieved relatively high growth. Although there was a slight decline in 2017, it restarted an upward trend after 2018.

Table 7. Environmental and institutional support for Zhangzhou's innovation ecosystem

Year	Environmental and institutional support
2004	0.17
2005	0.15
2006	0.13
2007	0.13
2008	0.13
2009	0.14
2010	0.16
2011	0.18
2012	0.26
2013	0.54
2014	0.59
2015	0.62
2016	0.69
2017	0.50
2018	0.55
2019	0.56
2020	0.59
2021	0.65
2022	0.69

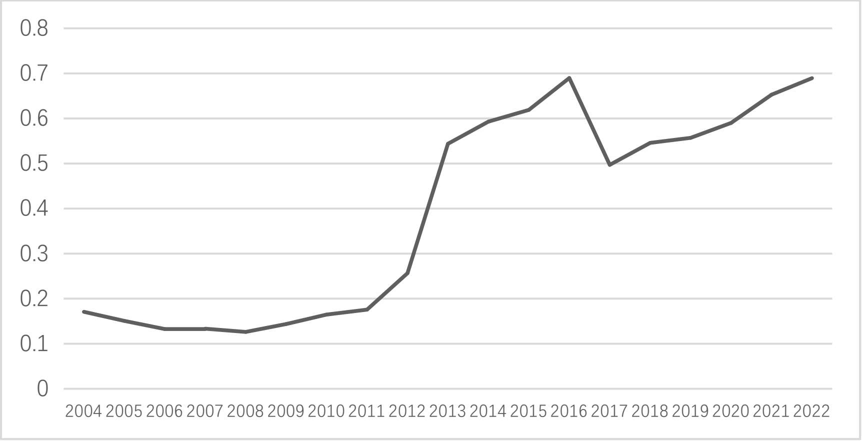

Figure 4. Changes in environmental and institutional support

4.3. Summary

The analysis of the above four dimensions reveals that, given the large fluctuations in the flow of innovation factors, the constantly increasing innovation capability and environmental and policy support are the reasons for the increase in the overall quality value of Zhangzhou's innovation ecosystem. Zhangzhou's innovation ecosystem is accumulating resources to cope with external shocks and, at the same time, is evolving through continuous learning and adaptation. Although the diversity of innovation subjects measured by the Shannon index has not changed significantly, the complexity and dynamics of the system are increasing. In addition, the large fluctuations in innovation factors may be caused by rapid changes and adjustments in the system and external shocks. In general, Zhangzhou's innovation ecosystem is in the growth stage and has not yet entered the mature stage.

5. Conclusions

This paper suggests that the resilience of the urban innovation ecosystem is affected by various factors, among which the interactions among innovation subjects, the mobility of innovation factors, and the institution construction within the system are critical. Therefore, this study uses life cycle theory to theoretically analyze the characteristic evolution of the urban innovation ecosystem, measures the spatiotemporal evolution of Zhangzhou's urban innovation ecosystem from 2004 to 2022, and uses various indicators to analyze the four levels of resilience. In this paper, through an analysis of the evolution process of the quality and characteristics of Zhangzhou's innovation ecosystem, the authors find the following conclusions:

First, latecomer cities in the process of regional integration need to pay attention to the siphoning effect of core cities to avoid the shock caused by the outflow of innovation factors.

Second, in the growth stage, the urban innovation ecosystem improves system quality mainly through the accumulation of resources and an increase in the innovation input-output ratio.

In summary, an innovation ecosystem is the key for urban economies to survive, develop, and prosper in a dynamically changing environment. For cities such as Zhangzhou, the problem is promoting the urban innovation ecosystem from the growth stage to the mature stage by constructing the institutional environment. The authors think that the enhancement of the vitality of the innovation ecosystem and the promotion of the sustainable development of cities should be based on the following suggestions:

First, the governance system related to the innovation ecosystem should be improved. Constructing an inclusive institutional environment should attract more innovative subjects and elements. Innovation subjects should be guided to increase responsible innovation behavior. Cooperation among innovation subjects should be promoted, and the relationships between innovation subjects should be regulated. The competitive relationships among companies provide good external conditions for innovation activities.

Second, the diversity and interaction level of the innovation subjects in the ecosystem should be enhanced. Make full use of the existing mechanisms to build a further open and shared industry-university research collaboration mechanism and cooperation and exchange platform to guide more SMEs to actively participate in it, promote the cross-border and cross-industry flow of knowledge and technology within the innovation ecosystem, and further promote innovation—the transformation and application of achievements in the industrial chain.

Third, society should be further guided in participating in the urban innovation ecosystem, establishing relevant digital asset trading platforms, building a market-oriented innovation financing system, and jointly investing in the construction of innovation infrastructure. The allocation and flow of innovation elements should be optimized through the participation of diverse stakeholders.

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Disclosure statement

The authors declare no conflict of interest.

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