Spatial Temporal Characteristics and Driving Forces of CHINA's Aircraft Industry

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Abstract. The development of China's aircraft industry remained an increasing concern from the government and the public. Using the GIS method and the panel data from 2006 to 2019, this study visualized the spatial temporal characteristics of the aircraft industry in China from the following perspectives: the concentration ratio, the R&D intensity and the comprehensive development level. The characteristics were summarized as follows: (1) Across China's 23 provinces and municipal cities, the average agglomeration degree maintained a relatively low level during the study period, but there was an uneven trend among different regions. The agglomeration degree was decreasing in traditional western production centers and increasing in the emerging eastern production centers. (2) The R&D intensity went up and down from year to year and varied significantly among different regions. (3) The comprehensive development scores in western China kept decreasing and those in eastern China maintained increasing.

Keywords: Temporal and spatial characteristics · Agglomeration degree · R&D intensity · Development level · Aircraft industry

1 Introduction

For some time now, the spatial redistribution of the aircraft industry attracts many concerns from governments and the public. Observing the facts that the entry or the exit of the aircraft industry in the specific region will promote or depress the economy, this focus is well-grounded. It is therefore important to uncover the spatial temporal characters of the aircraft industry and identify the driving forces behind those characters.

From a historical perspective, the spatial temporal patterns in different countries presented different characteristics. In the US, the spatial diffusion of the aircraft industry was in line with its industrialization spatial expansion. The aircraft industry of the US began in the northeastern region and drifted toward the south and the east. Seattle got a lot of government financial support for military aircraft manufacturing during the World War II. Thus, it became the headquarters of Boeing and the production and the R&D centers of the aircraft industry in the world [1]. In 2001, the headquarters of Boeing moved from Seattle to Chicago for lower tax rate and geographical proximity to markets. In 2009,

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the second production line of Boeing 787 has been established in South Carolina. All those signs indicated that the spatial distribution evolution of the aircraft industry in the US.

The spatial temporal characteristics of the aircraft industry in China were quite different from those of the US, which was in reverse with its industrialization diffusion [2]. Generally speaking, the spatial distribution of the aircraft industry had experienced three stages. The first stage (1960–1980), China started to establish its aircraft industry initiated by the Third-line Construction Campaign[1]. For the sake of national security, the aviation industry was mainly distributed in key investment "Third-line" cities, such as Xi'an in Shaanxi Province, Chengdu in Sichuan Province, Nanchang in Jiangxi Province and so on. Due to the role of "path dependence", the aviation industry in these areas expanded towards the early of 1980s. The second stage (1980–2000), with the deepening of market economic reform, the aircraft industry became an "isolated island" which had little connection with the local economy. The reason lied in that those key investment "Third-line" cities were all western and central cities with relative scare capital and technology resources, which violated the capital-intensive and technology-intensive nature of the aircraft industry. Therefore, in this stage, the distribution of the aircraft industry commanded by the central government caused a low-efficient development. The third stage (2000-now), after 2000, in order to make use of the advantages of skilled labor, technology and capital resources in the eastern region, China tried to relocate the aircraft industry distribution by introducing new production lines in the eastern provinces. In this context, Tianjin, Zhuhai and other eastern cities have been chosen as new key aircraft industrial base. The aircraft industries in these cities have achieved rapid development by introducing aircraft assembly lines and establishing national aviation industry parks.

At present, the central government attached great importance to the aircraft industry. According to *the medium and long-term development plan of the civil aircraft industry (2013–2020)*, the annual revenue of the aircraft industry will exceed 1 trillion RMB Yuan by 2020. This huge revenue attracted local governments at the provincial level to make concerted efforts to develop their own aircraft industry. A province may try to preserve or improve its own enterprises' market share by providing financial supports or other local incentive policies. In fact, about 23 provinces have some aircraft capacity.

Would the government support cause a low level of repeated construction or a high level of agglomeration in aircraft industry distribution? In this context, what were the unique characteristics of spatial temporal evolution of China's aircraft industry? And what were the driving forces behind the spatial temporal agglomeration evolution? The answers to these questions will help us to understand the reason behind the spatial temporal evolution of the aircraft industry and provide useful policy implications.

Compare with other high technology and capital intensive industries, the aircraft industry required for even larger scale of production and much intensive R&D investment. Previous literatures documented that the comprehensive development level of the aircraft industries were influenced mainly by the production scale and R&D intensity [3, 5]. Therefore, this study will uncover the spatial temporal characteristics from

[1] Third Line Construction: A large scale infrastructure construction, spanning from 1964 to 1980, focused on national defense, and industrial transportation.

three aspects: the agglomeration degree, the R&D intensity and the comprehensive development level.

The civil aircraft industry agglomeration attracted many concerns in the literature [6–9] (Edward and Usha, 2016). As an industry that tends to agglomerate and requires huge R&D inputs, the aircraft industry has been studied in the previous literatures mainly from two aspects: the agglomeration and innovation patterns. Some literatures investigated how the agglomeration of the aircraft industry came into being? Or identifying influencing factors of the aircraft industry agglomeration, but no consensus had been achieved [9–11]. A hand of literatures emphasized the importance of geopolitical ambitions during the early stage of aircraft agglomeration. After investigated the aircraft agglomerations in Montreal, Seattle, Toulouse and Toronto, Niosi and Zhegu [11] demonstrated during 1960s, the trade protection policy implemented by the US government contributed a lot for the early formation of the US aircraft agglomeration. Controversially, other literatures demonstrated market force was even more important than government attention in the aircraft industry development. By survey from selected aircraft firms, Romero [3] identified the manufacturing advantages were the driving forces for aircraft agglomeration in Mexico, and incentive policies play little role. Spreen [4] emphasized the importance of the domestic market for civil aircraft agglomeration and pointed out the failure of Japan and South Korea in aircraft mainly came from their small domestic demand and improper international marketing strategy. Steenhuis & Kiefer [5] investigated three possible driving forces of the early-stage agglomeration development in the State of Washington and identified the main driver was manufacturers-led coordinating mechanism, the other two possible drivers: incentive policy and government organization contributed little to the agglomeration development.

Another branch of literatures discussed the aircraft industry from the perspective of R&D. McGuire [6] investigated the important role of R&D played and found in the UK, during 1990's R&D as a percentage of sales in the aircraft industry was about 10% which was much higher than the average level (2%). Vértesy [12] held that the international R&D cooperation in aircraft industry was well above the average of other high technology industries, but it had a decline trend after 1990. Some studies explored the technology diffusion patterns. After investigated the aircraft industry in Montreal, Seattle, Toulouse and Toronto, Wagner & Walton [13] found that compared with local technology spillovers, international spillovers contributed more to the aircraft industry development. Using a sample of 300 aircraft from 1945 to 2000 and logistic regression method, [14] found that when firm resources available was not matched with the product resource requirement, the firm would develop new aircraft products through horizontal alliances with competitors, which will lead to a technology spillover among aircraft plants.

Studies about China's aircraft industry mainly focused on the comprehensive development level evaluation. Based on Porter's Diamond Theory, most studies first established an evaluation index system, and then using global principal components methods or factor analysis method to evaluate the comprehensive development level [15–17]. In addition, using Czamanski's method, Chu (2010) first identified the aircraft industry agglomeration in China.

Although the existing literatures had explored the aircraft industry from three aspects: the agglomeration, the R&D input and the development level of the aircraft industry, some points still require further attention. (1) Existing literatures only investigated the spatial temporal evolution and its driving forces of the aircraft industry from the perspective of agglomeration, which failed to explore the aircraft industry from the perspective of the R&D intensity and the development level. Since the R&D intensity and the agglomeration is crucially important for the development of the aircraft industry, it is necessary to investigate the aircraft industry from the three aspects together. (2) In previous literatures, most studies were conducted by survey or through personal interviews, few literatures analyzed by quantitative methods for lack of data. (3) Countries studied in previous literatures about the aircraft industry, mostly were about the US and the EU. Some studies concerned about Asian countries only involved Japan and South Korea, few studies concerned the aircraft industry agglomeration in China.

To better understand the spatial temporal evolution pattern of the aircraft industry in China and its driving forces, we visualized the spatial temporal evolution pattern of the aircraft industry using the GIS method and the panel data from 2006 to 2016, and then identified the driving forces behind the evolution patter. This research contributed to the existing literature in the following two ways. (1) By illustrated the spatial temporal evolution pattern of the aircraft industry from three perspectives: the agglomeration degree, the R&D intensity and the development level, this study found that there was a separation of production centers from R&D centers and the development level of the aircraft industry in the eastern region were improved much faster than that in western region. (2) The different driving forces behind the spatial temporal evolution pattern of the aircraft industry had also been identified. Therefore, this paper can not only provide a more accurate and complete understanding of the spatial temporal evolution pattern of China's aircraft industry, but also present some policy implication for aviation industry in the near future.

2 Indicator Selection, Data Sources and Methodology

2.1 Indicator Selection

Considering the characteristics of the aircraft industry and the availability of data, this paper established an evaluation index system to describe the development of the aircraft industry, which included three aspects: product supply, product demand and technology innovation. As an industry with increasing returns to scale, the aircraft industry needed sustained investment to maximize its profit. To describe the supply of aircraft products, this study used the following index: the total fixed assets, the number of aircraft enterprises and the number of staff. The demand of aircraft products can be measured by the total industrial output value, sales revenue, total profit and export value. Technological innovation was a huge driving force for the development of the aviation industry, which was represented by: R&D intensity and proportion of R&D staff.

2.2 Data Sources

The data for aircraft industry used in this paper were collected from China Civil Aircraft Industry Statistical Yearbook 2007–2020, which covered the data from 2006 to 2019 and was the longest study period the data available. The provinces and municipal cities covered in this Yearbook were varied from year to year, reflecting the aircraft industries moved out or in some specific provinces. For example, the Yearbook didn't cover the data of Tianjin from 2006 to 2009, and it excluded Anhui, Fujian, Gansu, Hebei, Henan, He Longjiang, Jilin, Shaanxi, Yunnan Provinces in 2016. Therefore, the panel data used in this study was unbalanced.

2.3 Methodology

2.3.1 Concentration Ratio of Industry

Many approaches can be used to measure the industry agglomeration degree, such as Spatial Gini Coefficient, Herfindahl index, EG index, etc. Based on the availability of data and the characteristics of the aircraft industry, we use the Concentration ratio of industry in this paper to measure the industry agglomeration degree. The Concentration ratio of industry can be measured by the ratio of industrial output (or R&D, sales, employment, etc.) in a specific region to that of the whole market. The concentration ratio of industry (CR_i) was calculated for 2006–2019 as Eq. (1). The larger of the concentration ratio of industry represented the greater degree of agglomeration. Theoretically, the CR above 10% in the specific region indicated the agglomeration had been formed in this region.

$$CR_{\mathrm{i}} = \frac{X_i}{\sum_{i=1}^{N} X_i} \tag{1}$$

where CR_i represented the concentration ratio of the aircraft industry in province i; X_i indicated the industrial output or employment in the province i, $\sum_{i=1}^{N} X_i$ represented the industrial output of the total market. In this study, in order to explore the concentration ratio of the aircraft industry comprehensively, two indicators (industrial output and R&D intensity) have been used to calculate CR_i. More specifically, CR_{ii} will be used to represent the industrial output concentration ratio and CR_{ir} will be used to represent the R&D intensity concentration ratio of the aircraft industry.

2.3.2 Factor Analysis Method

Through combining a large number of related factors into a small number of unrelated comprehensive indicators, i.e. common factors, Factor Analysis Method can be used to evaluate the comprehensive development situation of the aircraft industry. It can eliminate the correlation between the original indicators, avoid the duplication of information and overcome the subjectivity of weight determination, thus making the evaluation results more accurate and objective. We established the model of Factor Analysis Method as Eq. (2):

$$X_{p\times 1} = A_{p\times m}F_{m\times 1} + \varepsilon_{p\times 1} \tag{2}$$

where X represented an observable random vector; F was an unobservable random vector with m dimensions, called a common factor of X; ε was a special factor, each component of which represents the part of the original variable that cannot be explained by the common factor; A was the correlation coefficient between X and F, which indicated the degree of dependence of X_i on F_j. Generally, the number of common factors was determined according to variance contribution rate and cumulative variance contribution rate. More specifically, when the cumulative contribution rate of several common factors exceeded 85%, the other common factors can be ignored. Thus, the number of indicators can be simplified. Finally, the comprehensive score of the aircraft industry development can be calculated according to the Eq. (3).

$$F = \frac{\sum_j^n \lambda_{ij} x_{ij}}{\sum_j^n \lambda_{ij}} \tag{3}$$

where F was the comprehensive score of the aircraft industry development; λ refered to the eigenvalues of common factors; x_{ij} represented the common factors. The higher the F indicated the higher level of aircraft industry development and vice versa.

2.3.3 Standard Deviational Ellipse (SDE)

Standard deviation ellipse was a commonly used method for quantitative analysis of the overall characteristics of spatial distribution. It consisted of three elements: rotation angle θ, standard deviation along the main axis (long axis) and standard deviation along the auxiliary axis (short axis). The rotation angle θ reflected the main direction trend of the geographical elements distribution, the long axis indicated the discrete degree of geographical elements along the main direction trend and the short axis represented the discrete degree of geographical elements along the minor direction trend. Their mathematical expressions were as follows:

$$\theta = \frac{\left(\sum_{i=1}^n w_i^2 x\prime_i^2 - \sum_{i=1}^n w_i^2 y\prime_i^2\right) + \sqrt{\left(\sum_{i=1}^n w_i^2 x\prime_i^2 - \sum_{i=1}^n w_i^2 y\prime_i^2\right)^2 + +4\left(\sum_{i=1}^n w_i^2 x\prime_i^2 y\prime_i^2\right)^2}}{2\sum_{i=1}^n w_i^2 x\prime y\prime} \tag{4}$$

$$\delta_x = \sqrt{\frac{\sum_{i=1}^n \left(w_i x_i' \cos\theta - w_i y_i' \sin\theta\right)^2}{\sum_{i=1}^n w_i^2}} \tag{5}$$

$$\delta_y = \sqrt{\frac{\sum_{i=1}^n \left(w_i x_i' \sin\theta - w_i y_i' \cos\theta\right)^2}{\sum_{i=1}^n w_i^2}} \tag{6}$$

$$\overline{X_w} = \frac{\sum_{i=1}^n w_i x_i}{\sum_{i=1}^n w_i} \tag{7}$$

$$\overline{Y_w} = \frac{\sum_{i=1}^n w_i \mathrm{y}_i}{\sum_{i=1}^n w_i} \tag{8}$$

where θ was the rotation angle, representing the angle of the North direction clockwise rotation to the longitudinal axis of the ellipse. $(x_1, y_1)\ldots(x_i, y_i)\ldots(x_n, y_n)$ meant the coordinates of point elements. w_i represented the weight, x'_i, y'_i indicated the coordinate deviation of point elements x_i, y_i from the mean center respectively. δ_x, δ_y were the standard deviation of x axis and y axis. $(\overline{X_w}, \overline{Y_w})$ represented weighted mean center.

Table 1. Evaluation indexes of aircraft industry in cities of China

First rank index	Second rank index	Unit
Aircraft product supply	Number of enterprises	/
	Number of staff	/
	The total fixed assets	Hundred million RMB
Aircraft product demand	Total industrial output value	Hundred million RMB
	Sales revenue	Hundred million RMB
	Total profit	Hundred million RMB
	Export value	Hundred million RMB
Technology innovation	R&D intensity	%
	Proportion of R&D staff	%

3 Spatial Temporal Characteristics of CHINA's Aircraft Industry

Using the above method and the data described in Table 1, this paper calculated the CR_i and the comprehensive development score of aircraft industry in China from 2006 to 2019. We analyzed the spatial temporal characteristics of the aircraft industry from the following three aspects: agglomeration degree, R&D intensity as well as development level.

3.1 Time Series Characteristics of the Aircraft Industry

Promoted by the national strategy, the aircraft industry had developed rapidly since 2000. Figure 1 presented the agglomeration degree (CR_{ii}), the R&D intensity, the development level and the industrial output from 2006 to 2019, which showed although the trends of the four indexes in the study period were different from each other. The industrial output maintained a steady increasing trend during the study period. The annual average industrial output swelled from 2674.98 million RMB in 2006 to 14710.34 million RMB in 2019, with an average annual increase of 34.61%; the R&D intensity increased even more rapidly than the industry output, which increased from 3.22 in 2006 to 32.48 in 2019, with an average annual increase of 69.85%, but its increasing trend was not as smooth as the industry output. It resumed their upward trajectories after huge downticks in 2009, 2013 and 2016. The reason might exist in the fact that compare to the industrial output, the R&D intensity can be more deeply influenced by government incentive policies which was volatile from year to year. Unlike the industrial output and the R&D intensity, the CR_{ii} remained almost unchanged with a slight fluctuation around 4.54 from 2006 to 2015, which reflected that the CR_{ii} was difficult to change because of the industrial inertia. Remarkably, the CR_{ii} soared to 7.14 in 2016. That might be explained by the fact that there were only data of 14 provinces presented by China Civil Aircraft Industry Yearbook in 2016, while there were data of 20–23 provinces given in other years. The fewer numbers of provinces involved in aircraft manufacturing, the higher CR_{ii} would be. The development score maintained stable and fluctuated around the zero, which indicated that the comprehensive development level improved little during the study period. That might be explained by the unbalanced development of the aircraft industry in different regions. Although the aircraft industry developed rapidly in some provinces, such as Tianjin and Guangdong, while in other provinces the aircraft industry was in decline. Thus, the average development level for the whole country seemed unchanged. It was worth noting that there had been a sharp increase of the industrial output since 2010. The reason might exist in the fact that in 2010, the central government implemented a series of incentive policies and introduced several important projects. For example, in 2010, Opinions on China's Low Altitude Airspace Management Reform was implemented. In the same year, the Airbus A320 assembly project was introduced in Tianjin, the helicopter headquarters of Aviation Industry Corporation of China also established in Tianjin, and Xizi Aircraft spare parts project with an annual industrial output of 1 billion RMB settled in Hangzhou Dajiangdong Industrial Cluster Area, Zhejiang.

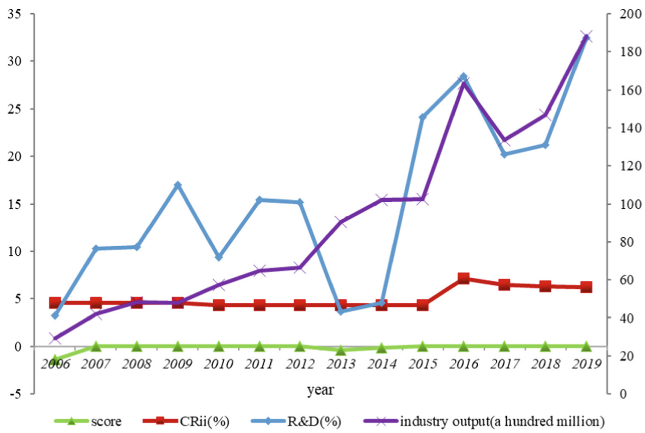


Fig. 1. The trend of the development of the aircraft industry during 2006–2019

3.2 The Spatial Temporal Pattern Evolution of the Aircraft Agglomeration

The civil aircraft industry had a trend of agglomeration because of its increasing return of scale nature. To investigate the agglomeration of the aircraft industry, the average CR_{ii} and CR_{ir} from 2006 to 2019 have been calculated in this study. There were totally three provinces' annual average CR_{ii} above 10% during the study period, which indicated the agglomeration degree of aircraft had been formed in those three provinces, i.e., Shaanxi, Liaoning and Sichuan. Jiangxi ranked the forth with a CR_{ii} of 6.92. Table 2 compared four aircraft industry production centers in China.

As shown in Table 2, Shaanxi, Liaoning and Sichuan were three traditional production centers, for in 2006 the industrial output of the three provinces were all above 10%. On one hand, the industrial output of the first three production centers accounted for 44.74% of the total industrial output, which revealed the tendency of preliminary agglomeration of the aircraft industry in China. On the other hand, the agglomeration degree of the aircraft industry was still at a relatively low level. Among all the production centers, Shaanxi, as the largest production center (measured by CR_{ii}), it only accounted for 22% of the total industrial output. Table 2 also indicated the eastward movement of the aircraft industry in China. The industrial output of Shaanxi was significantly higher than that in Liaoning and Sichuan in 2006. In 2006, the industrial output of Shaanxi was two times higher than that in Liaoning, 1.6 times higher than that in Sichuan, which indicated that Shaanxi was the most important production center in terms of industrial output in 2006. However, at the end of the study period, the agglomeration degree in western regions was decreasing. In 2019, the industrial output of Sichuan ranked first among four production centers, the industrial output in Sichuan only 1.29, 1.95 and 2.37 times than that of Shaanxi, Liaoning and Jiangxi. Respectively. During the study period, CR_{ii} of Shaanxi decreased remarkably, CR_{ii} of Liaoning maintained almost unchanged. In contrast, CR_{ii} of Jiangxi increased sharply from 4.06 to 8.68, with an increase rate of 214%.

Compared with CR_{ii}, CR_{ir} in the four production centers were even much lower. The annual average CR_{ir} was far below 10 for all those four productions. In 2006, CR_{ir} in Shaanxi and Liaoning was slightly above than 10.

Table 2 revealed two facts: (1) During the study period, the advantage of traditional aircraft productions, i.e. Shaanxi, Liaoning and Sichuan had been diminishing, while the emerging aircraft production, i.e., Jiangxi developed rapidly. (2) Although being the largest production centers, R&D input in Shaanxi, Liaoning, Sichuan and Jiangxi were still low.

3.3 The Spatial Temporal Pattern Evolution in the Comprehensive Development Level

Employed the Factor Analysis Method, we calculated the comprehensive development score (F) to measure the aircraft industry development level, then visualized it by GIS in Fig. 2. Generally speaking, during 2006–2019, only 10 from 23 provinces and municipalities' comprehensive scores were above 0, which indicates the development of the aircraft industry in those 7 provinces were better than the mean level. Those 10 provinces and municipalities were Shaanxi, Sichuan, Guizhou, Jiangsu, Liaoning, Fujian, Tianjin, Beijing, Henan and Guangdong. Among which, the score in Shaanxi, Sichuan, Jiangsu and Liaoning had a decreasing tendency and the score in Guangdong and Tianjin had a tendency of increase during the study period.

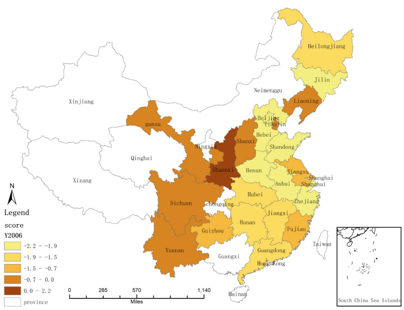
As shown by Fig. 2a, according to the comprehensive score, the 22 aircraft producing provinces and municipalities were divided into 5 levels. Specifically, Shaanxi ranked the first level; Liaoning, Gansu, Sichuan, Yunnan and Shaanxi belonged to the second level. The other provinces or municipalities were all below the second level. Among which, Shanghai and Zhejiang with comparatively abundant capital and technology belonged to the lowest development level. It reflected the fact that the aircraft industry developed much better in the previous "Third Line Construction" provinces than in other provinces in 2006. Until 2006, the spatial distribution of the aircraft industry had still been influenced by the "Third Line Construction Campaign".

Table 2. Comparison of the aircraft industry productions in China from 2006 to 2019

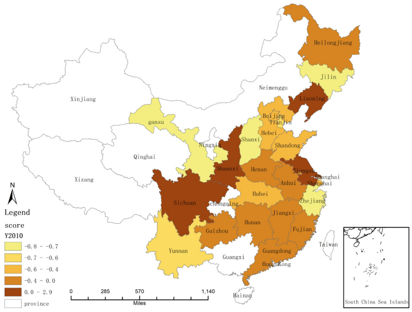
Region	Industrial output (million RMB)			R&D intensity			CRii (%)			CRir (%)		
	2006/	2019	Mean	2006/	2019	Mean	2006/	2019	Mean	2006	2019	Mean
Shaanxi	16819	54158	36926	7.07	19.76	10.48	27.34	16.01	21.33	12.16	3.38	3.85
Liaoning	8273	35831	22772	8.23	6.92	7.48	13.45	10.59	13.09	8.23	1.19	1.61
Sichuan	10151	69698	26470	3.00	10.86	3.00	16.50	20.60	13.95	4.44	1.86	2.81
Jiangxi	2501	29383	14381	0.66	57.88	10.09	4.06	8.68	6.92	0.98	9.90	4.15

As shown by Fig. 2d, in 2019, the spatial distribution of the aircraft industry had changed a lot compared to that of 2006. In 2019, Shaanxi, Guangdong and Sichuan ranked the first level. Yunnan, Fujian, Jiangxi, Henan, Hebei, Shaanxi, Beijing, Liaoning and Jilin belonged to the second level. Guangzhou, Hunan, Shanghai and Jiangsu belonged to the third level. Hubei, Shandong and Heilongjiang belonged to the fourth level. It revealed the fact that the previous key aircraft industrial bases constructed during the "Third Line Construction" were losing their advantage, as the comprehensive scores in Shaanxi, Liaoning, Sichuan and Guizhou had been decreasing. It also indicated that the aircraft industry in eastern regions developed rapidly.

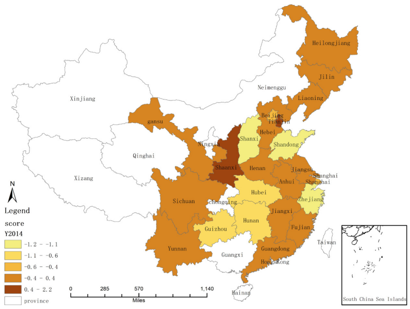
In addition, the comprehensive development scores of provinces around the 4 production centers—Shaanxi, Sichuan and Guangdong, were relatively low which showed the already formed production centers, neither the traditional centers nor the emerging centers had played a leading role and promoted the development of aircraft industry in their surrounding area. This phenomenon was similar to the aircraft agglomeration in Mexico where a bunch of aviation manufacturing enterprises shared a common locality but without close interaction [3].



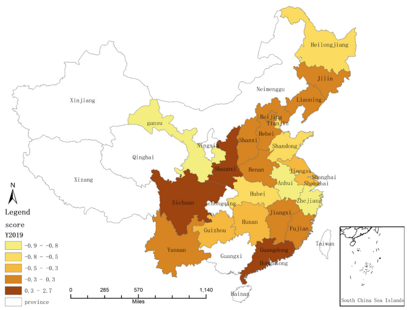
(a) 2006



(b) 2010



(c) 2014



(d) 2019

Fig. 2. Spatial temporal pattern of the aircraft industry in China

3.4 The Spatial Temporal Evolution in the Aircraft Industry Agglomeration and R&D Intensity

As shown by Fig. 3 and Table 3, the standard deviation ellipses of the agglomeration degree and the R&D intensity of the aircraft industry changed a lot from 2006 to 2019. In terms of the agglomeration degree, the standard deviation ellipses were mainly concentrated in the southwest, the central and the northeast China, which indicated most of the aircraft industry production centers located in the southwest and the central China. Its scope changed little from 2006 to 2009, but expanded from the southwest to the northeast after 2009, which reflected that the spatial distribution of the aircraft production centers remained unchanged before 2009 and began to expand from the southwest to the east after 2009. The reason lied behind this transformation was that around 2009 the central government took a series of incentive policies to foster the new aircraft center in eastern regions. For example, in 2008, the national Civil Aircraft Industrial Park in Tianjin Binhai New Area has been established. Airbus A320 Aircraft Assembly Line has been in operation in Tianjin since 2008. The rotation angle θ changed little, violating from 38.46 degrees in 2006 to 34.48 degrees in 2019, which reflected that during 2006–2019 the spatial distribution of aircraft industry production centers was distributed northeast-southwest. The main reason might be that as for the great industrial inertial, it was difficult for the aircraft industry to change its space distribution in a short time. As for the shape of the standard deviation ellipse, both the short and the long axis of the standard deviation ellipse of the industry agglomeration showed a cyclic trend. More specifically, the short axis decreased first (2006–2010) and then increased (2010–2014). Contrarily, the long axis first increased (2006–2010) and then decreased (2010–2014), which indicated that the spatial distribution of the production centers of aircraft industry presented a trend of contracting first and then expanding in the East-West direction, and a trend of expanding first and then contracting in the South-North direction.

Table 3. Standard deviation ellipse parameters of the aircraft industry distribution

		CR_{ii}			R&D	
Year	XStdDist	YStdDist	Rotation	XStdDist	YStdDist	Rotation
2006	633509.72	1107591.34	38.46	524326.76	947888.42	24.96
2010	577064.77	1230313.3	40.25	682944.80	1021299.97	31.09
2014	610250.61	1060846.04	29.2	530189.57	636992.42	13.09
2019	668554.45	1133444.79	34.48	539480.36	725924.75	38.80

Compared with the industry agglomeration degree, the rotation, the long axis and the short axis of the standard deviation ellipses of the R&D intensity were much more volatile during the study period. Specifically, the short axis of the R&D intensity was decreasing sharply from 2006 to 2016, which indicated a very rapid concentration of the R&D intensity of the aircraft industry in the East-West direction. The long axis of the R&D intensity increased slightly from 2006 to 2012 and then decreased sharply from 2012 to 2016, which reflected a trend of expanding first and then contracting in the South-North direction. In addition, the rotation of R&D intensity experienced even much larger fluctuation than that of the industrial output. It swelled from 7.02 in 2012 to 143.44 in 2016, which reflected unlike the industrial output, the spatial distribution of aircraft industry R&D centers can be changed in a short time. Furthermore, Fig. 3 also showed the production center was separated from the R&D center and the eastward trend of the R&D center was much faster than the industrial output center. Especially in 2016, Shanghai has become the undoubted R&D center. The reasons might exist in the following two facts: (1) Although the established industrial equipments, plants as well as the labor pool cannot be relocated in a short run, the R&D input was more likely to fluctuate with the incentive policy; (2) the Eastern China had more abundant capital and technology resources, which made it easier for the aircraft industry in the eastern region to access and acquire these resources. Therefore, it was an obvious separation of the production center from the R&D center.

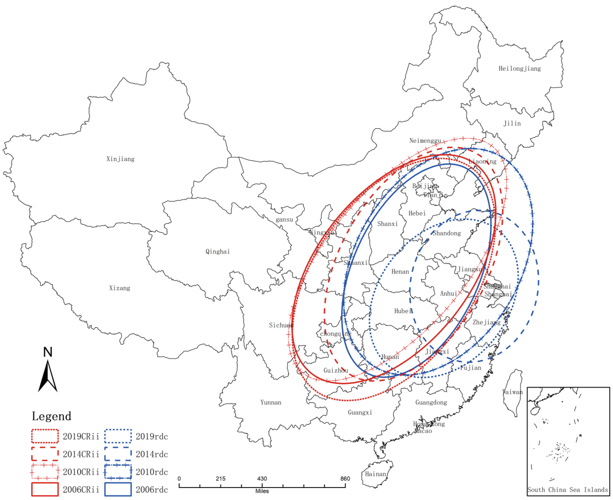


Figure. 3. Comparison between CR_{ii} and R&D input of the aircraft industry in China

After analysis the spatial temporal evolution of aircraft industry, we found the following spatial temporal evolution characteristics for the development level, agglomeration and R&D intensity of China's aircraft industry: (1) The overall agglomeration degree of the aircraft industry presented a low level during the study period, although that in some eastern regions were increasing. (2) The development level of the West was higher than the East in 2006, while this advantage of the West had been diminishing during the study period; (3) The production center and the R&D center had a trend of moving from the West to the East; (4) The production center centers and R&D centers were separated from each other. The production center centers were located in the western and the central China, while the R&D centers were more likely located in the East, represented by Shanghai.

4 Conclusions and Implications

The development of the aircraft industry has raised many concerns. Using the GIS technology and the panel data from 2006 to 2019, this paper visualized the spatial temporal characteristics of aircraft industry in China from the perspective of the following three aspects:

(1) Comparative with the US, the agglomeration degree of the aircraft industry in China was still in a low level and improved little during the study period. As the largest aircraft production center, Shaanxi's agglomeration degree of the aircraft industry was only 21.33% during the study period. In 2000, the agglomeration degree of the US' aircraft industry was 49.9% from a global perspective view [11]. Theoretically, the higher degree of agglomeration, the aircraft industry will be more likely to benefit from economies of scale, labor pool and knowledge spillovers. There was still a long way for China to go before it can break the duopoly of Boeing from the US and Air bus from the EU. In addition, from a spatial perspective, the agglomeration degree experienced an uneven development among different regions. Specifically, the agglomeration degree in western regions was decreasing during the study period and that in eastern regions were increasing.
(2) The R&D intensity went up and down from year to year and varied significantly among different regions. As a high technology industry, the R&D intensity of the aircraft industry was much higher than that of other industries. In 1994, the Gross Expenditure on R&D (% of GDP, GERD) in the UK was 2.19, while its R&D intensity in the aircraft industry in the UK reached 11.1. In 2016, the Gross Expenditure on R&D (% of GDP) in China was 2.11 which was almost equal to the level of UK's GERD in 1994, its R&D intensity in aircraft industry in that year reached 27.12 which was much higher than that of the UK. However, this figure was only 3.07 and 6.68 in 2014 and 2015, respectively. In addition, the R&D intensity was extremely unbalanced among regions. Generally speaking, the R&D intensity of eastern regions was much higher than western and central regions. During the study period, Shanghai (111.62) and Hunan (17.78) ranked first and second in terms of R&D intensity, while Yunnan (0.48) was among the least R&D intensity regions.
(3) The development level of the aircraft industry was somewhat like the agglomeration degree. During the study period, the average development level for the whole country remained unchanged. However, the development level among different regions presented quite a different trend. At the beginning of the study period, the development level of the West was higher than the East, while the gap between the west and the east had been diminishing at the end of the study period, which also indicated that the diffusion of the aircraft industry production centers of the aircraft industry in China were moving from the West to the East.

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