Review of Economic Assessment

Homepage: https://anser.press/index.php/REA

Spatial-temporal Evolution of Global Aircraft Production Network: Evidence from 1741 Global Aircraft Firms

Ying She [a], Guoliang Liu [a], Ling Jia [a], Yangu Deng [a, *], Liyuan Zhang [b]

[a] *School of Economics and Management, Nanchang Hangkong University, Nanchang, China*

[b] *School of Business and Creative Industries, University of the West of Scotland, Paisley, UK*

ABSTRACT

Triggered by the rising demand, a complex aircraft production network has been evolving during the past half century. In order to analysis the spatial-temporal evolution of this network, this paper establishes a novel and complex data by collecting 1774 major global aircraft manufacturers' production relationship from Jane's All the World' s Aircraft Development & Production (1965-2021), and visualizes the spatial temporal characteristics of the global aircraft production network by using Social Net Analysis method. The characteristics are summarized as follows: (1) the main aircraft firms from 48 counties form a complex production network centered on the United States, Europe and China; (2) The production network remains diffusion during 1965-2005, but it retracts after 2005, which documents evidences of de-globalization trend in the aircraft industry; (3)AVIC, Airbus, Boeing, Textron, Lockheed, Kawasaki, Mitsubishi, Sikorsky, Bell, and Embraer are all ranked high in the study period and play the role of leading firms in the production network and drive the cooperative connections of other companies.

KEYWORDS

Global aircraft production network; Social network analysis method; Spatial characteristics; Major nodes

* Corresponding author: Yangu Deng
E-mail address: dengyangu@nchu.edu.cn

ISSN
doi: 10.58567/rea02010003

Received 23 January 2023; Accepted 30 March 2023; Available online 23 April 2023

1. Introduction

The spatial redistribution of the aircraft industry attracts many concerns from governments and the public (OECD, 2014; Gangi, et. al, 2022). Observing the facts that the development of the aircraft industry in the specific country is associated with economy prosperity and national security, this focus is well-grounded (Pritchard, 2002; Landoni, 2019). The past 70 years have witnessed serious reorganization and change in the global aircraft industry. Especially, a series of issues, such as de-globalization, the Covodia-19 pandemic, the trade friction between the US and China, the Russia-Ukraine war threatens the stability of the supply chain of the aircraft industry. Under the new global theme of "development and security", European and US governments are aggressively de-hydrocarbonising Russia and accelerating de-commoditization of East Asia, promoting supply chain security based on diversification of suppliers, localization nearshoring and friend-shoring (Rozhkov, et. al, 2022). In this context, it is therefore important to answer the following questions? What are the characteristics of the aircraft production network? And how stable of the global aircraft production network is? By using the main global aircraft firm-level data and Social Network Analysis method (SNA), this paper aims to explore the characteristics of the global aircraft network.

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 (Romero, 2011; Essletzbichler 2015). In order to reduce technology and investment barriers, a more complex production network comes into being in the past century. This network is dominated by few world oligopolies attached with numerous small suppliers. Previous literatures documents that the reorganization process of the global aircraft industry during the past century (Esposito and Raffa 2007; Clifton et. al, 2011; Turkina et. al, 2016). In general, the development of the aircraft industry has gone through four stages: (1) the period of complete monopoly in the United States after World War II-1960 (Fauri, 2021) (2) the period of catch-up in Europe from 1960 to 1980; (3) the period of duopoly in Europe and the United States from 1980 to 1990; and (4) the period of technology diffusion from 1990 to the present. In this process, the focus of research gradually changed from "how to develop the aircraft industry in Europe and America" to "whether the latecomer countries (Brazil, India, Japan, Korea, China) will always remain subcontractors of parts and components for European and American aircraft manufacturing, or whether they can form a complete independent aircraft industry by overcome technical and financial barriers and become competitors of Europe and the United States" (Niosi &Zhegu, 2005; Steenhuis & Kiefer, 2016; Ardito, etc.al, 2016).

In terms of Asian practices, Japan, South Korea, and Taiwan, China has all attempted to establish complete aircraft production capabilities. Japan began developing and producing its own civil aircraft, the YS-11, in 1950; South Korea formed a 14-company commercial aircraft development consortium (KCDC) led by Samsung, which proposed to establish the Asian Express with China to manufacture regional jets(Park&Lee, 2012); Taiwan also tried to establish a regional jet production capacity with the 1990s by purchasing by purchasing commercial aircraft production lines from McDonnell-Douglas and British Aerospace Corporation (BAC) (Garrette, et. al, 2009). However, the above efforts all ended in failure, and existing research believe that the reasons lies in: government subsidies for production squeezed out private investment, small domestic markets, inappropriate international marketing strategies, the reluctance of Europe and the United States to sell complete aircraft production lines for military security reasons, and the inability of Asian countries to cooperate internationally as European countries do (McGuire, 1999; McGuire& Islam, 2015; Lee, J. J., & Yoon,2015). This shows that the aircraft industry is different from other high-tech industries in terms of technology spillover and organization. Therefore, the production network of the aircraft industry is more complex than other industries.

Among Asian countries, China is the only one with a complete aircraft production capacity. The development of China's aircraft industry has been a process of mutual cooperation and competition with Boeing and Airbus. The existing literature attributes the realization of the Chinese aircraft industry's complete aircraft production capacity to the huge domestic aircraft market, good technology absorption capacity, and government incentives (Samuels, 1996).

The methodology of the study has been extended from the early quantitative methods such as interviews and case studies to qualitative analysis methods such as principal component analysis and Czamanski. In addition, there are also studies that focus on the volatility of China's airport shipping stock index to analyze business behaviors that may affect the aviation industry (Liu et al., 2020). However, throughout the changes in research thinking, how the aircraft industry innovates and develops has been a hot issue and the core of research, and a lot of pioneering research has been conducted mainly from the perspectives of key influencing factors, industrial agglomeration, technology spillover, and technology development path, etc. It is found that the aircraft industry is vastly different from other high-tech industries in all these aspects.

A large body of literature has explored the key influencing factors for the development of the aircraft industry, but no consensus has been reached. Some studies have emphasized the decisive role of government will in the development of the aircraft industry. Niosi & Zhegu (2005) argue that the protective trade policies implemented by the U.S. government and the EU's involvement in the formation of Airbus with high subsidies and other means of government support are directly responsible for the formation of the U.S.-European aircraft duopoly. Some studies have also argued that the first firms (anchor firms) are the core force driving the development of the regional aircraft industry (Romero, 2011; Steenhuis & Kiefer, 2016; Zhu et al., 2020). The changing level of agglomeration, internet technology are also identified as a key factor for the aviation ecosystem (Huang et al., 2022; Zhao & Li, 2021).

Another branch of literature discusses the evolution of aircraft cluster. The formation of industrial clusters in the aircraft industry is mainly due to the local specialized labor force and preferential government policies, rather than intra-regional technology spillover. For example, Monsey compared the importance of the three agglomeration mechanisms of labor, upstream and downstream relationships, and knowledge sharing, and find that the former two were more important (Monsey, 2011). And Isaksen find that with the support of the Norwegian government's industrial policies, six internationally competitive industrial clusters have been developed (Isaksen, 2009).

Technology spillover methods and technological innovation paths are also a hot topic in the field of aircraft industry research. The channels of aircraft industry spillover are: FDI, international trade, supply chain management, and international inter-technical cooperation. Most studies believe that technology spillover in the aircraft industry is different from other high-tech industries, and it does not occur through cooperation between local manufacturers, but more through cooperation or subcontracting with large international aircraft industries, or through government subsidies for R&D. In addition, the aircraft industry can be divided into three tiers from the perspective of the industry chain: complete aircraft assembly (Airbus, Boeing, Bombardier, helicopter Textron, Embraer and Eurocopter), power plants (General Electric, Pratt&Whitney, Rolls-Royce), and electronic components, hydraulic systems and airframe parts. Finally, studies have found that small subcontractors cannot easily adapt existing technologies and products, and when large producers in Tier 1 and Tier 2 develop new models, the original small subcontractors are often unable to keep up with the pace of technological updates, while providing opportunities for new firms to join the chain (Clifton et al., 2011; McGuire & Islam, 2015). Finally, the type of industrial agglomeration also affects the way technology spillovers occur. Aircraft industrial clusters are classified as industrial complex, axial, Italian, Marshall, urban hierarchical, and social network, and different types of industrial clusters differ in terms of firm interactions, management focus, organizational structure, and the way technology spills over (Edward &Usha, 2016; David et al., 2019).

Although the existing literatures have focused on the reorganization during the past century, 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 characteristics of global aircraft production network. (2) In previous literatures, most studies were conducted by survey or through personal interviews, few literatures analyzed by quantitative methods for lack of data.

In this context, this paper constructs a global aircraft manufacturing production network based on Jane's dataset from 1965 to 2021 from the perspective of GPN, and also analyzes the spatial and temporal evolution characteristics of the global aircraft manufacturing production network structure from a long time period and global space perspective using social network analysis, so as to clarify its evolution law and identify the network structure The paper also uses social network analysis to analyze the spatial and temporal evolution of the global aircraft manufacturing network structure from a long time and global spatial perspective.

Compared with the existing literature, the possible marginal contributions of this paper are as follows: (1) unlike the existing literature that portrays aircraft production networks in terms of patent cooperation and airport routes, this paper discusses the structural characteristics and spatio-temporal evolution of aircraft production networks from the perspective of networks constructed by three types of cooperative production relationships among micro manufacturers: joint ventures, mergers and acquisitions, subcontracted production and strategic alliances, which enriches and expands the scope of research in the field of aircraft. (2) this paper is the first to use firm- level data to construct a global aircraft production network, which better portrays the changes of cooperative relationships among manufacturing firms, enriches the content of aircraft network research, and provides new empirical evidence for the study of global aircraft production networks.

The remainder of this paper is organized as follows: the second part explains the main research methods and data sources used in this paper; the third part is the empirical results and analysis of the characteristics of the global aircraft production network structure; the fourth part is the main conclusions and discussion of this paper's research.

2. Data sources and methodology

2.1. Data sources

This study focuses on the structural characteristics of the production network of global aircraft manufacturing manufacturers and their spatial and temporal development patterns, so this paper needs to identify the cooperative production relationships among aircraft manufacturing manufacturers and construct a global aircraft manufacturing production network based on them. This paper mainly uses Jane's All The World's Aircraft (Jane's), which is compiled by Jane's Group (UK). Jane's All The World's Aircraft ("Jane's") and text-mined the data contained therein to meet these requirements.

The Yearbook contains a wide range of detailed company information and technical data on the world's major aircraft manufacturers. The core data is collected and compiled exclusively by Jane's, including company name, address, year of establishment, number of employees, manufacturing partners, customer information and product information. In order to accurately represent the spatial and temporal evolution of the global aerospace manufacturing production network, we selected Jane's Yearbook data for six time periods: 1965-1966, 1974-1975, 1984-1985, 1991-1992, 2004-2005, 2020-2021, containing a total of 129, 207, 200, 190, 475 and 540 manufacturing companies respectively.

Therefore, these data meet the needs of this paper to construct a global aircraft manufacturing production network, and provide a data basis for this paper to analyse the spatial and temporal evolution characteristics of the global aircraft manufacturing production network.

2.2. Construction the global aircraft production network

We construct the global aircraft production network by digging and using the cooperative information from Jane's World Aircraft (2020-2021). First, in order to accurately identify the cooperative production relationships among aircraft manufacturing companies, the cooperative production relationships in Jane's Almanac are defined as the following three types: joint venture, in which two companies establish a new company or acquire another company in order to engage in the production of a certain product; subcontracting, which refers to the oligopoly outsourcing the non-core technical components to suppliers; strategic cooperation, which means the two firms cooperatively research and develop a new type of the aircraft or some new key technologies. Therefore, if there is one of the above behaviors, it is considered that there is a cooperative production relationship between two companies. According to the cooperative information, we can construct the global production network in the aircraft industry.

Then, the country, name, abbreviation, address, year of establishment, and number of employees of each aircraft manufacturing company in Jane's dataset are added to complete the information, in order to analyze the spatial and temporal distribution characteristics of the production network of global aircraft manufacturing companies from the perspective of long time period and global space.

According to the knowledge of graph theory, the aircraft manufacturing manufacturers are abstracted as nodes and their cooperative production relationships are abstracted as the connecting lines between nodes, thus representing the social network as a collection of graphs. Since the cooperative relationship between cooperative manufacturers is bi-directional and the cooperative relationship as an edge does not have weights, this paper adopts an undirected and unweighted network graph. Therefore, in this paper, in order to accurately identify the cooperative production relationships among aircraft manufacturers, each manufacturing manufacturer in Jane's yearbook is used as a node in the network, and then the cooperative production relationships among manufacturers sorted above are used as the connecting lines between nodes. Therefore, the network of global aircraft manufacturing companies is constructed for 2021.

2.3. Methodology

2.3.1. Network density

The network density can reflect the closeness of the global aircraft production network. The greater the network density, the closer the connection between the aircraft manufacturers and the greater the impact of the aircraft production network on each manufacturer. The network density formula is as follows.

$$D = \frac{2m}{n(n-1)} \tag{1}$$

Where D represents the density of aircraft production network, m indicates the actual number of current relationships in the network, and n indicates the number of aircraft manufacturers contained in the aircraft production network.

2.3.2. Network density

Network centrality includes point degree centrality, betweenness centrality, and closeness centrality which are used to describe the network structure. Point degree centrality represents the position of the manufacturer in the production network and measures the importance of the manufacturer in the production network. The higher the point degree centrality means the manufacturer has more connections with other manufacturers in the aircraft production network, and also indicates this manufacturer locates in the center of the production network. The point degree centrality can be calculated as equation (2):

$$C_{Di} = \sum_{j} \delta_{ij} \tag{2}$$

where C_{Di} represents the point degree centrality of the aircraft manufacturer, which indicates the strength of inter-manufacturer connections. It equals 1 when there is a cooperative relationship from aircraft manufacturer i with aircraft manufacturer j. Otherwise, it equals 0 which means there is no cooperative relationship.

2.3.3. Betweenness centrality

Betweenness centrality reflects the ability of the manufacturer to control other manufacturers. The higher the degree of betweenness centrality, the more the firm can control the mutual actions of other firms, and also indicates the firm is at the center of the network. The degree of betweenness centrality can be calculated according to the equation (3):

$$C_{Bi} = \sum_{j<k} \frac{g_{jk}(i)}{g_{jk}} \tag{3}$$

Where C_{Bi} is the betweenness centrality of an aircraft manufacturer; gjk is the number of shortest paths that exist between manufacturer j and manufacturer k, and gjk(i) is the number of shortest paths that pass through manufacturer i between manufacturer j and manufacturer k.

2.3.4. Closeness centrality

The closeness centrality reflects the degree of independence of an manufacturer in the production network from the control of other firms. The higher of the closeness centrality, the more the manufacturer is not influenced by other manufacturers, and also means that the manufacturer is not at the center of the network. The closeness centrality can be calculated according to the equation (4):

$$C_{pi} = \sum_{j=1}^{n} d_{ij} \tag{4}$$

Where C_{pi} represents the closeness centrality of an aircraft manufacturer, and dij is the shortest path length between manufacturer i and manufacturer j.

3. Spatial temporal characteristics of China's aircraft industry

3.1. Preliminary analysis

3.1.1. Time series characteristics of the aircraft industry

This paper collects the establishment time and numbers of the global main aircraft manufacturers from Jane's Yearbook 1965-1966, 1974-1975, 1984-1985, 1991-1992, 2004-2005, 2020-2021. The Figure 1 shows the establishment time of aircraft manufacturers during 1900-2021.

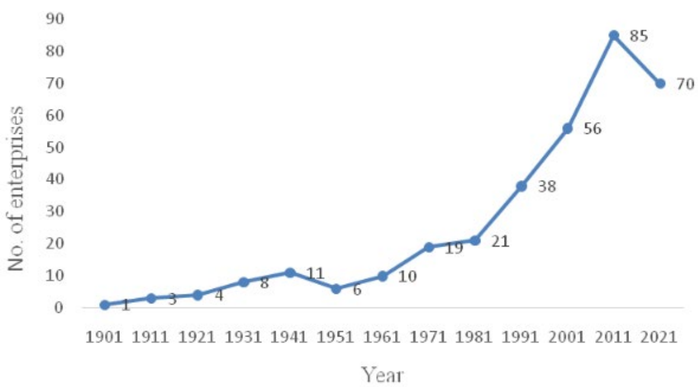

Figure 1. The trend of new establishment of the aircraft manufacturers during 1900-2021.

From Figure 3-2, it can be seen that the aircraft manufacturing manufacturers have generally shown a significant growth trend over the past 100 years, which can be divided into three stages: (1) Start-up during the two World War (1900-1950). This period starts from the first airplane invented by Wright Brothers in the United States in 1903. Then, an aircraft manufacturing boom emerged in Europe and around the world. Since 1907, when the world's first aircraft factory was established by the Voisin brothers in France, the number of new aircraft manufacturing manufacturers increased below 10 every 10 years; in 1911, Feng Ru moved the "Guangdong Manufacturing Machinery Company" founded in the United States back to China. In 1916, Boeing, the most influential company in the history of the aircraft industry, was founded. The main reason for the slow growth of the number of companies during this period is that most countries around the world have not yet completed the industrialization process and are not yet able to support the aircraft industry, which requires high technology and high investment. (2) Rapid growth in the globalization period (1950-2010). Along with the completion of industrialization in developed countries, the aircraft manufacturing industry gained rapid development. From the new establishments of 21 in 1980 to 85 in 2010, the number of new manufacturers expanded by four times in 30 years. Among them, the Second World War greatly stimulated the development of the aircraft industry. The U.S. established its leading position in the global aircraft industry. The Soviet Union also built a complete national aircraft research system during this period and became one of the strongest countries in the aircraft industry besides the United States, and the Russian aircraft industry is still thriving today. The rapid growth of civil aircraft after World War II, influenced by military aircraft production, coupled with the rapid progress of science and technology, and the increasingly fierce competition between the two camps, mainly the U.S. and the Soviet Union, led to the booming of the world aircraft industry, and the number of aircraft companies in various countries around the world increased dramatically during this period. (3) Slow growth in de-globalization period (2008-present). After 2008, influenced by the financial crisis the growth rate of aircraft industry began to decline. There have been only 70 new more established aircraft manufactures since 2010. This period witnessed a worldwide merge and acquisition (M&A). For example, Lockheed Martin and Boeing conducted 20 and 40 M&As, respectively, between 2008 and 2016. Airbus has kept conducting M&As to enhance its competitiveness. In addition, in order to maximize economic efficiency, large aircraft manufacturers have reorganized their industrial chains and outsourced components to suppliers in low-cost countries or regions.

3.1.2. Space characteristics of the aircraft industry

In order to describe the space characteristics of global aircraft manufactures, we visualize the distribution of global aircraft manufacturers by ArcGIS analysis method. First, we collect the manufacturer addresses from the Jane's World Aircraft (2021). Then, using the Google Map interface get the latitude and longitude coordinates of the manufacturers.

As shown in Figure 2, the global aircraft manufactures clusters in several countries. Although the aircraft manufacturing manufacturers are distributed across 48 countries, they are mainly concentrated in EU, USA, China and Russia. There are only a few aircraft manufacturing manufacturers locates in the remaining countries. Preliminary analysis shows a core-edge production network in the global aircraft industry with the EU, the US, China, and Russia in the center.

In order to further analyze the uneven distribution of aircraft manufactures across countries, we sum up the number of aircraft manufactures in every country. Figure 3 presents the result, which shows that the E.U. (31%), the U.S. (25%), China (11%) and Russia (9%) rank the first four positions among all countries.

3.2. Aircraft production network structure

3.2.1. Network structure

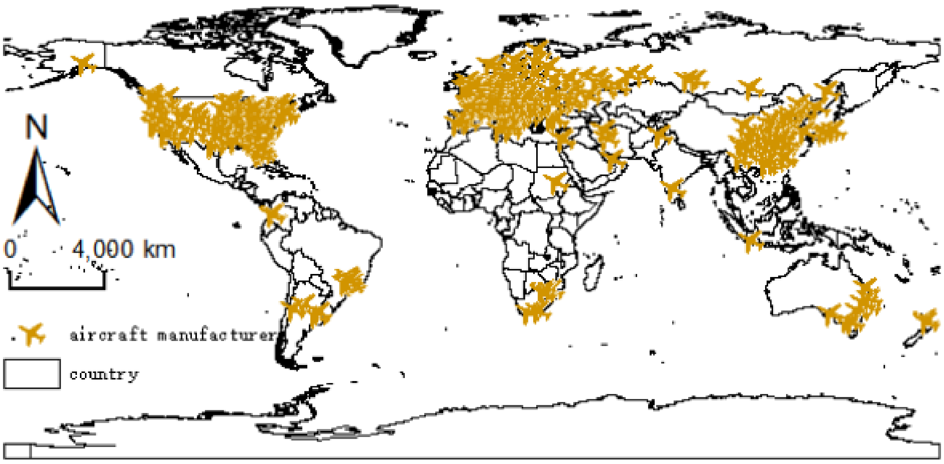

Figure 2. The distribution of global aircraft manufacturers in 2021.

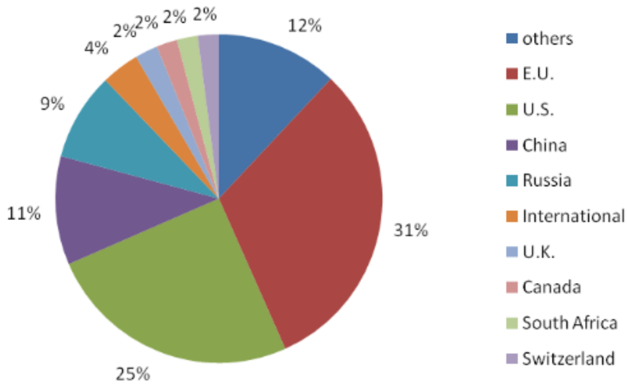

Figure 3. The Country distribution of global aircraft manufacturing companies.

Employed the above SNA method and data mentioned in Section 2, we get the spatial connection matrix of global aircraft production network according to their cooperative relationship, and use Gephi to visialize the structure of global aircraft production network for the year of 2021. Figure 4 shows the network structure. We can see Boeing (U.S.), Airbus (E.U.), Lockheed (U.S.), Silorsky (U.S.), AVIC (China), Bombardier (Canada) have the most connections in the production network.

3.2.2. Network density

The network density is a good indicator of the development and the evolution of the network. The network density and standard deviation are calculated in Table 1. The network density for all six years ranges from 0.01 to 0.03, indicating that the relationship between countries in the aircraft production network is very loose and not close. The reason might lie in that the share of key technology among trade partners might threaten national security. This political concern lowers the cooperation willingness between the aircraft manufacturers across countries, especially in the area of the airplane engine (Zheng et al., 2023). The results show also shows that the network density decreases from 1965 to 1985, and experience a slight increase from 1985 to 1991, then keep decreasing again from 1991 to 2021. The reason might lie in the organizational form of global aircraft manufacturing experienced three stages: industrial district, supply relationships and strategic alliances (Esposito and Raffa 2007).

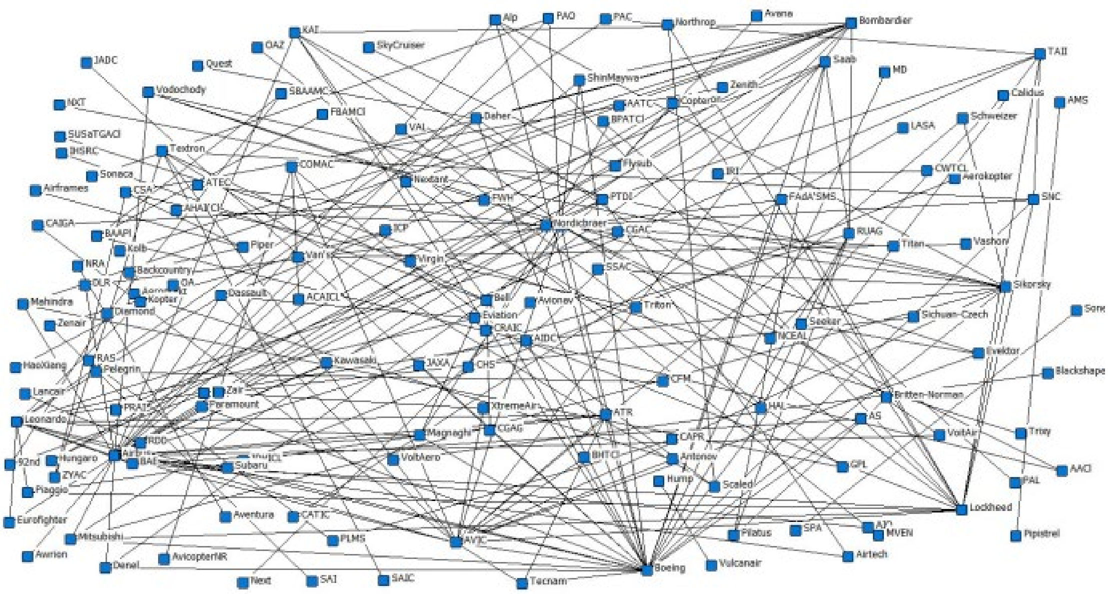

Figure 4. Aircraft production network structure for 2020-2021.

In the stage of industrial district, firms merge with the local people and other local firms. 1980s and 1990s experience a rapid globalization. Highly industrialized countries subcontract low-technology products to labor intensive countries. Thus, in the above two stage the network density remains relatively high. The sample examination period. However, in the strategic alliances stage, leading companies find that there are some new aircraft firms are getting steadily stronger in low-cost countries and gain specialized know-how after being suppliers for a long time. In order to uphold these potential future competitors and strengthen their own leading position, the oligopolies in the aircraft industry are forced to reduce allies. Therefore, in this stage we see a decreasing trend of network density. That is also in line with the globalization process and de-globalization. 1980s and 1990s witnessed a high speed global specialization. In this process developed countries subcontract low-technology products to developing countries to benefit from their low-cost labor. Our result also documents that the de-globalization is happening in the global aircraft production network.

Table 1. Global aircraft network density from 1965 to 2021.

Year	1965	1975	1985	1991	2005	2021
Network density	0.0353	0.0331	0.0234	0.0306	0.0158	0.0103
S.D.	0.1890	0.1788	0.1525	0.1756	0.1494	0.1094

3.2.3. Centrality Analysis

This section analyzes the centrality of the network by measuring the point centrality, closeness centrality, and betweenness centrality indicators of the aircraft production network from 1965 to 2021, and examines the position of each firm in the aircraft production network. Because of the large number of firms, only the top 10 ranked firms are selected for illustration.

3.3. Degree Centrality

Table 2 shows the degree centrality of the top 10 firms during the study period with the mean degree centrality of 2.3 in 1965, 40% of the total manufacturers are above the mean level; this figure increases slightly to 3.2 in 1975 with 36% of the total manufacturers are above the mean level; the number remains almost the same in 1985 and

1991 with 29%, 34% of the total are above the mean respectively; the figure jumps to 4.5 in 2005 with 26% of the total manufacturers are above the mean level; in the year of 2021, this degree decreases back to 2.9 with 27% manufacturers above the mean level. This result indicates: (1) From 1965 to 1991, there is a higher degree of manufacturers' connectedness, i.e., firms having more connections with other firms with leading manufacturers have a less influential. However, after 1991 leading firms have more influence accompanied while attached small firms have less connection with each other. Among all aircraft manufacturers, Kawasaki, Mitsubishi, Bell, Lockheed, and Sikorsky are ranked at the top of the degree centrality in all six time periods, indicating that they are all in a more central position in the global aircraft production network. In addition, after 2000, Airbus, Boeing, and AVIC all ranked in the top three positions because their production relationships not only lie among the aircraft companies in the countries where they are located, but also take full advantage of their technological strengths, and they are at the center of the global aircraft production network with the aircraft companies they cooperate with in production worldwide.

Table 2. Degree centrality of global aircraft network from 1965 to 2021.

1965			1975			1985		
manufacturers	centrality	rank	manufacturers	centrality	rank	manufacturers	centrality	rank
Kawasaki	6	1	Lockheed	11	1	Boeing	18	1
NIHON	6	2	Bell	9	2	Lockheed	18	2
Bell	5	3	Boeing	9	3	Bell	10	3
Fairey	5	4	Fokker	8	4	Mitsubishi	8	4
Lockheed	5	5	HAWKER	8	5	Aeritalia	7	5
Mitsubishi	5	6	Kawasaki	7	6	Kawasaki	7	6
Sikorsky	5	7	Aeritalia	6	7	Aerospatiale	6	7
SAOADLB	4	8	CAC	6	8	Airbus	6	8
BAC	3	9	Shin	6	9	CAS	6	9
Boeing	3	10	AGUSTA	5	10	Dassault	6	10
1991			2005			2021		
manufacturers	centrality	rank	manufacturers	centrality	rank	manufacturers	centrality	rank
Lockheed	17	1	AVIC	53	1	Airbus	32	1
Boeing	13	2	Boeing	34	2	Boeing	30	2
Airbus	11	3	Airbus	23	3	AVIC	24	3
Aerospatiale	8	4	Bombardier	23	4	Embraer	18	4
Nihon	8	5	Embraer	16	5	Bombardier	17	5
Dassault	7	6	Agusta	15	6	Leonardo	14	6
Mitsubishi	7	7	Honeywell	14	7	Lockheed	14	7
Textron	7	8	Textron	14	8	Sikorsky	12	8
Bell	6	9	Bell	13	9	RUAG	9	9
Kawasaki	6	10	Sikorsky	13	10	AIDC	7	10

3.4. Closeness Centrality

Table 3 shows the closeness centrality of the top 10 firms during the study period, ranked from smallest to largest because the higher the closeness centrality. A higher score indicates the firm is at the edge of the production network. Generally, the closeness centrality is becoming larger during the study period which reflects the core firms are losing control on other firms. The results show that these below-average companies are the closest to the centre of the global aircraft production network and are more central to the network. From 1965 to 2021, the leading firms in the aircraft industry have changed. Sikorsky, Mitsubishi and Kawasaki have been losing their control of other firms while AVIC, Boeing and Airbus have become the first three firms independent from others, playing the role of central actors in the network and being able to connect more quickly with other companies and establish partnerships.

Table 3. Closeness centrality of global aircraft network from 1965 to 2021.

1965			1975			1985		
manufacturers	closeness centrality	rank	manufacturers	closeness centrality	rank	manufacturers	closeness centrality	rank
Sikorsky	120	1	Lockheed	133	1	Boeing	214	1
Mitsubishi	121	2	Bell	139	2	Lockheed	224	2
Kawasaki	128	3	Boeing	142	3	CAS	228	3
Fairey	131	4	Hawker	142	4	SONACA	236	4
Bell	134	5	CAC	144	5	Embraer	239	5
JAMC	134	6	Kawasaki	148	6	SIS	239	6
NIHON	135	7	Fokker	151	7	Aeritalia	243	7
AISA	136	8	CASA	154	8	Hawker	243	8
Lockheed	137	9	Agusta	156	9	Kawasaki	244	9
WAL	139	10	Aeritalia	157	10	Mitsubishi	244	10
1991			2005			2021		
manufacturers	closeness centrality	rank	manufacturers	closeness centrality	rank	manufacturers	closeness centrality	rank
Lockheed	157	1	AVIC	463	1	AVIC	883	1
Boeing	162	2	Boeing	468	2	Boeing	897	2
Aerospatiale	167	3	Agusta	512	3	Airbus	903	3
Mitsubishi	169	4	Textron	513	4	Embraer	914	4
Kawasaki	173	5	Sikorsky	521	5	Leonardo	921	5
Nihon	174	6	Airbus	525	6	Sikorsky	925	6
APL	176	7	Bombardier	527	7	Bombardier	926	7
Airbus	176	8	Antonov	530	8	Dassault	938	8
CAE	180	9	AID	534	9	KAI	938	9
SAC	180	10	Ilyushin	534	10	AIDC	940	10

3.5. Betweeness Centrality

The mean betweenness centrality in 1965 is 29.43 and 29% of the total manufacturers are above the mean level; in 1975 this figure jump to 42.74 with 40% of the total manufacturers higher than the mean level; in 1985 it continues increasing to 64.40 with 29% manufacturers higher than that; in 1991 it decreases slightly to 50.45 with 24% above the mean level; in 2005 it soars to 143.99 with 23% above the mean; and in 2021 it is 94.48, about 24% above the mean. Table 4 shows the betweenness centrality of the top 10 firms during the study period. The results show that: (1) The mean level of betweeness centrality keep increasing which indicates node firms have more influence on neighbouring firms and are able to make more connections with other companies from 1965 to 2021. However, the number of firms above the mean level is decreasing which reflects less firms have power to influence other firms. Lockheed, Boeing, Kawasaki, Mitsubishi, Sikorsky, Bell, Hawker and Embraer are the leading companies in the study period, indicating that these companies are at the centre of the global aircraft production network and are able to establish contacts with other aircraft companies to carry out collaborative production and other activities. The result also shows that in 2021 the top companies in the network are AVIC, Airbus, Embraer, Boeing and Textron, which have a much higher betweenness centrality than the other companies, indicating that they are at the centre of the network.

4. Conclusions and implications

4.1. Conclusions

Table 4. Betweenness centrality of global aircraft network from 1965 to 2021.

1965			1975			1985		
manufacturers	betweenness centrality	rank	manufacturers	betweeness centrality	rank	manufacturers	betweeness centrality	rank
Sikorsky	198.567	1	Lockheed	243.240	1	Boeing	764.441	1
Fairey	181	2	Bell	217.051	2	Lockheed	482.165	2
Mitsubishi	113.5	3	Hawker	157.672	3	Aeritalia	316.380	3
SAOADLB	77	4	Boeing	148.502	4	Embraer	229.758	4
NIHON	64.849	5	CAC	144.875	5	AVIC	224	5
Bell	63.450	6	RRL	128.519	6	CAS	198.781	6
Kawasaki	60.416	7	Fokker	119.818	7	Dassault	183.981	7
Lockheed	56.333	8	CASA	110.696	8	Hawker	181.313	8
JAMC	46.25	9	Kawasaki	99.678	9	Aerospatiale	181.184	9
AISA	34.066	10	Dassault	94.966	10	PAC	171	10
1991			2005			2021		
manufacturers	betweenness centrality	rank	manufacturers	betweeness centrality	rank	manufacturers	betweeness centrality	rank
Lockheed	496.496	1	Boeing	2699.139	1	AVIC	1890.975	1
Boeing	313.99	2	AVIC	2685.482	2	Airbus	1267.493	2
Aerospatiale	225.904	3	Textron	1392.636	3	Embraer	1212.842	3
Dassault	202.387	4	Antonov	1080.829	4	Boeing	1197.427	4
Airbus	201.702	5	Ilyushin	1076.556	5	Textron	941.502	5
Mitsubishi	156.024	6	Sikorsky	947.194	6	AACl	576	6
Textron	145.1	7	Embraer	769.321	7	ZYAC	576	7
Nihon	119.881	8	Sukhoi	720.845	8	CSA	492	8
SAC	116.032	9	Mil	651.113	9	BAAPl	489	9
UTP	93.086	10	Agusta	518.569	10	Bombardier	428.637	10

The reorganization of the aircraft industry globally has raised many concerns. Using Jane's Yearbook data 1965, 1975, 1985, 1991, 2005 and 2021, this paper first constructs a global aircraft production network. Then, employing SNA we examine the spatial-temporal evolution characteristics of the global aircraft production network. The main research findings are as follows.

4.1.1. In terms of network structure characteristics

The global aircraft manufacturing industry formed an aircraft production network centered on the United States, Europe and China across 48 countries.

4.1.2. The network density remains a stable increase trend during 1965-2005

But it begins decreasing after 2005, which indicates that the production network retracts. It is can be explained by the three stages of aircraft organization: industrial district, supply relations and strategic alliances. It is also in line with the globalization and de-globalization trend.

4.1.3. In terms of network centrality

Kawasaki, Mitsubishi, Bell, Lockheed, and Sikorsky all rank high in terms of degree centrality during the study period; after 2005, a stable structure centered on Airbus, Boeing, and AVIC are formed; AVIC, Airbus, Boeing, Textron, Lockheed, Kawasaki, Mitsubishi, Sikorsky, Bell, and Embraer are all ranked high in the study time period and are able to play the role of actors in the network and drive the cooperative development of other companies.

4.2. Implications

Based on the novel and complex data by collecting 1774 major global aircraft manufacturers' production information, this study identifies the cooperative production relationships and establishes a global aircraft manufacturing production network. The social network analysis method is used to explore the core enterprises in the global aviation manufacturing production network, which makes a beneficial exploration of the overall structure characteristics and spatial-temporal evolution of the aircraft production network. The future research can divide the the global aircraft production network into sub-networks according to production relationships, such as joint venture, subcontract and cooperative development. The mechanism of how the global aircraft production network come into being is another aspect that can be further explored.

Funding Statement

This research received no external funding.

Declaration of Competing Interest

The authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Acknowledgments

The major portion of this study was supported by Jiangxi Key R & D Projects of Science and Technology Department (No. CA201909375), Jiangxi University Humanities and Social Sciences Project Fund (No. JJ20112), Open Fund of Nanchang Hangkong University (No. ER202109330).

References

Ardito, L., Messeni Petruzzelli, A., & Panniello, U., 2016. Unveiling the breakthrough potential of established technologies: An empirical investigation in the aerospace industry. Technology Analysis & Strategic Management, 28(8), 916-934.

Arne Isaksen. Innovation Dynamics of Global Competitive Regional Clusters: The Case of the Norwegian Centres of Expertise[J]. Regional Studies,2009,43(9).

Chu, B., Zhang, H., Jin, F., 2010. Identification and comparison of aircraft industry clusters in China and United States. Chinese Geographical Science, 20(5), 471-480.

Clifton, N., David, R., Ehret, O. & Pickernell, D., 2011. An Analysis of Actual and Potential Clustering Structures, Stakeholder Governance Activities and Cross-locality Linkages in the Welsh Aerospace Industry, European Planning Studies, 19(2): 279-309

Esposito, E., Raffa, L., 2007. Global reorganisation in a high-technology industry: the aircraft industry. International Journal of Globalisation and Small Business, 2(2), 166-184.

Fauri, F., 2021. The Italian State's Active Support for the Aircraftal Industry: The Case of the Caproni Group, 1910–1951. Business History Review, 95(2), 219-247.

Gangi, F., Mustilli, M., Daniele, L. M., & Coscia, M. 2022. The sustainable development of the aerospace industry: Drivers and impact of corporate environmental responsibility. Business Strategy and the Environment, 31(1), 218-235.

Garrette, B., Castañer, X., Dussauge, P, 2009. Horizontal alliances as an alternative to autonomous production: Product expansion mode choice in the worldwide aircraft industry 1945–2000. Strategic Management Journal, 30(8), 885-894.

Huang, L., Zhong, Z., Wu, X., The impact of civil aviation industry agglomeration on high-quality economic development: a threshold regression model test based on provincial panel data. Journal of Beijing University of Aeronautics and Astronautics (Social Science Edition).

Jordi Jofre-Monseny, Raquel Marín-López, Elisabet Viladecans-Marsal. The mechanisms of agglomeration: Evidence from the effect of inter-industry relations on the location of new firms. Journal of Urban Economics,2011,70(2).

Jose Jr L A, Brintrup A, Salonitis K. Analysing the evolution of aerospace ecosystem development. Plos one, 2020, 15(4): e0231985.

Landoni, M., 2019. Convergence of innovation policies in the European aerospace industry (1960–2000). Technological Forecasting and Social Change, 147, 174-184.

Lee, J. J., & Yoon, H., 2015. A comparative study of technological learning and organizational capability development in complex products systems: Distinctive paths of three latecomers in military aircraft industry. Research policy, 44(7), 1296-1313.

Liu J,Qiao P,Ding J, et al. Will the Aviation Industry Have a Bright Future After the Covid-19 Outbreak? Evidence From Chinese Airport Shipping Sector. Journal of Risk and Financial Management, 2020, 13: 1-2.

McGuire, S., 1999. Sectoral innovation patterns and the rise of new competitors: the case of civil aerospace in Asia. Industry and Innovation, 6(2), 153-170

McGuire, S., and Islam, N., 2015. Indigenous Technological Capabilities, Emerging Market Firms and the Aerospace Industry. Technology Analysis & Strategic Management 27 (7): 739–758.

Niosi, J., Zhegu, M., 2005. Aerospace clusters: local or global knowledge spillovers? Industry & Innovation, 12(1), 5-29.

OECD. 2014. The Space Economy at a Glance 2014. Paris: OECD Publishing.

Park, Y., Lee, S. 2012. Patent Analysis for Promoting Technology Transfer in Multi-Technology Industries: the Korean Aerospace Industry Case. The Journal of Technology Transfer 37 (3): 355–374.

Pritchard, D. J., 2002. The global decentralization of commercial aircraft production: Implications for US based manufacturing activity (Doctoral dissertation, State University of New York at Buffalo).

Romero, J. M., 2011. Centripetal forces in aerospace clusters in Mexico. Innovation and Development, 1(2): 303-318.

Rozhkov, M., Ivanov, D., Blackhurst, J., & Nair, A. 2022. Adapting supply chain operations in anticipation of and during the COVID-19 pandemic. Omega, 110, 102635.

Steenhuis, H. J., Kiefer, D., 2016. Early stage cluster development: a manufacturers-led approach in the aircraft industry. Competitiveness Review, 26(1), 41-65.

Turkina E, Van Assche A, Kali R. Structure and evolution of global cluster networks: evidence from the aerospace industry. Journal of economic geography, 2016, 16(6): 1211-1234.

Zhao, W., Li, F. Research on the Impact of the Internet on Civil Aviation Strategy.Technical Economy and Management Research, 2021, (2): 101-105.

Zheng, X., Liu, Q., Zhao, Z. Technical barriers to trade with China and national economic security. International Economic Review, 2023 (01): 131-151+7-8.

Zhu, Y., Song, X., Yan, W., et. al Research on Shaanxi Aviation Industry Upgrading Strategy Based on TRIZ Theoryg. Research on Science and Technology Management, 2020, 40(3): 155-162.