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Dynamics of the global aerospace chain: A graph theory analysis

Dinámica de la cadena global aeroespacial: un análisis de teoría de grafos

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Abstract

This study aims to analyze, the changes that have taken place in global aerospace trade in the last 25 years, using a global chains value perspective and theory of graphs. Trade patterns are identified in which the leading countries, although they decentralize the production, those changes do not alter their leadership conditions. Countries such as Canada and China, which have not integrated into the global chain of the industry in a traditional way, have become in leaders, while countries such as Mexico that have been integrated in the chain following the theory of technological upgrading, have remained lagged behind the production of the lower value segments.

JEL Code: F14, O25, L93
Keywords: aerospace industry; global value chains; graph theory

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Resumen

Este estudio analiza mediante teoría de grafos y con la metodología de cadenas globales de valor, los cambios ocurridos en el comercio aeroespacial global en el último cuarto de siglo. Se identifican patrones de comercio en los que los países líderes, si bien descentralizan una parte de la producción, dichos cambios no alteran sus condiciones de liderazgo. Países como Canadá y China, que no se han integrado a la cadena global de valor de la industria en forma tradicional, se han convertido líderes, mientras que países como México que se han integrado en la cadena siguiendo la teoría del upgrading tecnológico, se han quedado rezagados a la producción de los segmentos más bajos de valor de la cadena

Código JEL: F14, O25, L93
Palabras clave: industria aeroespacial; cadenas globales valor; teoría de grafos

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Introduction

The aerospace industry (AI) is one of the most dynamic globally. Airbus (2018) estimates that in twenty years, the number of aircraft required to transport people and goods will be slightly less than double the total existing fleet in 2018. This will give rise to quantitative changes in production and the configuration of the production of goods and services linked to the industry. In recent years, greater demand for flights, the increase in air traffic, changes in the composition of the global production chains of the sector, and national policies to promote the industry have substantially modified aerospace production and trade.

This study analyzes global AI changes during the last 24 years and the national policies that caused them. The aircraft production process stages range from research to development, design, production, assembly, marketing, and after-sales services. Because each of these stages does not occur in a single geographic location, AI is defined as a global production chain. Therefore, it is convenient to use Global Value Chains (GVC) as the theoretical basis for the analysis of the sector.

The methodology used to analyze AI trade flows in the world is a graph or network theory. In principle, this theory makes it possible to analyze the main trade nodes, the direction of flows, the trade balance of each country, trade partners, and changes in trade patterns over time. This methodology provides analytical inputs to understand the productive and commercial strategies followed by the leaders. This work is structured in the following manner. The next section illustrates the theoretical approach to GVCs and reviews the studies that have analyzed AI from this perspective. The third section develops the graph or network methodology. The fourth section analyzes, applying the methodology, global aerospace trade at three points in time: 1995, 2005, and 2017. The selection of these years makes it possible to track the most significant changes in aerospace trade patterns in the world and understand the national policies that gave rise to them. This section pays special attention to the leading countries and Mexico. Finally, section 4 offers the conclusions of the study.

Review of the literature

The global economic liberalization that began in the mid-1970s gave rise to important changes that substantially modified trade relations between countries, generally associated with competitive advantages and patterns of historical development. It replaced them with relations involving the exchange of intermediate goods, machinery, and technology between transnational companies. The above gave rise to global trade organized in value chains, which currently account for just under 80 percent of world trade. The general trend of this trade pattern is the incorporation of a high number of imports per exported unit of product (Dickens 2011, pp. 7; Gereffi et al., 2005; 2016; Ortiz-Ospina et al., 2018).

The changes in trade patterns also modified the idea of development on the part of emerging economies, which replaced the old import substitution patterns with the development of certain industries linked to the international dynamics of GVCs. The expectation was that such integration would produce positive spillover effects on growth, mainly led by the export sector. In this context, the starting point is that intra-company transactions are cheaper and more efficient (since they are not subject to the costs of trade policies). The above reduces transaction costs and makes production processes more efficient (Williamson, 1979; 1975). It also implies changes in companies' governance structure, i.e., changes in internal functional processes to produce goods and services (Gereffi et al., 2005; Williamson, 1979).

The value chain concept focuses on analyzing the set of activities, processes, and phases that companies carry out to produce goods and services. These processes range from research and development to design, production, marketing, sales, after-sales, and recycling. The concept seeks to analyze the interaction between buyers and producers that directly affects the governance of the chain and gives rise to a given industrial structure (Gereffi et al., 1994; 1999; 2005).

This approach aims to analyze industrial reorganization issues, coordination, governance, and power in the chain that result in a certain distribution of value production globally (Gereffi et al., 2005). The above enables the development of analytical tools that make it possible to "generate effective policy instruments, related to industrial upgrading, economic development, job creation, and poverty reduction" (Gereffi et al., 2005, pp. 79; 2018).

The methodology makes it possible to establish a geographic orientation in an input-output structure and identify the central actors and leading companies and their structure and interaction with the productive and public policy context. It also analyzes the local institutional context of the agents integrated into the chain and the determining factors for establishing a productive upgrading strategy (Gereffi et al., 2016). The analysis of the institutions and organizations involved makes it possible to visualize the restrictions that local companies face in the global industry, which opens up the possibility of implementing modifications in the productive internal structure and institutional design to strengthen local suppliers incorporated in the value chain. The constraints identified in various studies constitute historical industrial or public policy lags in the countries' productive structure, infrastructure, business environment, and institutions that support that structure. By identifying these constraints, it is easier to address them within the framework of designing certain product development policies (PDPs) that allow local organizations to be integrated with value chains to establish upgrading possibilities (Gereffi, 2018).

One way to evaluate the aerospace industry through the GVC approach is to use the Transnational Alliances (TCA) model as a public development policy and analyze whether the configuration of an upgrading strategy has positive implications on the position of countries within the chain or in international trade. In this context, it is important to analyze whether the leadership of the chain and, therefore, the possibilities of developing countries to climb the chain are feasible to modify the governance structure. Moreover, it is also important to know whether the most profitable segments of the chain have organizational structures concentrated in a few companies located in the leading countries that protect the ownership of knowledge with barriers to entry or through trade agreements that prohibit direct competition. The above implies that the upgrading strategy is limited from the outset and that the countries that follow it will not be able to position themselves in the production of higher value-added segments. If this happens, the model of transnational alliances will prolong the gap in the chain, deepening asymmetries through specific requirements in a framework of high regulation in terms of property rights, certifications, and process standardization. There may be relative changes in the leadership of the main players at the country level, but it does not allow the entry of new competitors.

In the particular case of the aerospace industry, knowledge is restricted by a set of regulations and certifications that constitute the main barrier to entry. According to Deloitte (2018), the leading AI companies according to their 2017 revenues were Boeing, Airbus Group, Lockheed Martin, General Dynamics, United Technologies, GE Aviation, Northrop Grumman, BAE Systems, Raytheon, and Safran. This set of companies represents more than 60% of revenues worldwide and is responsible for the design, final assembly, and delivery of aircraft (Sturgeon et al., 2013).

At the national level, in 1995, 80% of global aerospace trade was concentrated in five countries (United States, Germany, Japan, France, and United Kingdom); in four countries by 2005 (United States, Germany, Canada, and United Kingdom); and in six countries by 2017 due to the entry of China and Canada in the production of various aircraft and components with a strategy diametrically different from that proposed by the GVC methodology. The above represents a significant sample of the limited mobility at the country level that such a strategy permits.

Leadership is linked to property rights to design. This notion is based on research and development (R&D) strategies and ultimately ends up defining each stage of the chain through the aircraft systems' technical specifications. As a result, the chain segments in which developing countries have a place are subject to the technical specifications of the former, making real upgrading impossible.

The same is true of education and training for chain integration; this is limited to meeting the needs of leading companies in the context of specific technical requirements and certifications. In the case of Mexico, the influence of transnational corporations (TNCs) is significant. Therefore, a productive ecosystem has developed around the needs of the leading corporations, with the immediate consequence that non-integrated firms are marginalized from supply and participation in the chain. (Sturgeon et al., 2011; Sandoval, 2013).

Mexico's strategy is based on an analytical approach that assumes that the greater the volume of exports, the greater the economic growth. Although in accounting terms this may be correct, in real terms, for this to happen, all the production for export would have to be generated internally, which is not the case in organized GVC markets (Sturgeon, 2011). Although the above is recognized, the integration strategy seeks to develop capabilities in Mexican companies that will enable them to upgrade in a network toward higher-value segments within the chain (Sturgeon & Memedovic, 2011).

At the national level, there is a broad set of analytical studies of the aerospace industry. However, these studies tend to focus on spatial aspects (regional or state studies) or the characteristics and skills of the workforce of the sector; such is the case of the studies by Hualde et al. (2007) and Salinas-García (2012). Some others analyze innovation capabilities, competitiveness, and knowledge transfer (Brown et al., 2013; Flores et al., 2017; Cypher et al., 2013), and another group of studies tends to focus on historical and developmental aspects of the aerospace sector (Casalet, 2013; López Galindo et al., 2018). From these works, some of the main internal problems that Mexican AI faces emerge. Among them are human capital formation, access to credit, improvements in trade flows, and linkage and implementation of learning processes (Domínguez et al., 2018; Vázquez & Bocanegra, 2018).

Methodology

To analyze the structure and recent evolution of aerospace trade and its main actors at the country level, this study uses the United Nations Conference on Trade and Development Stat global trade database. The data are analyzed using graph theory, making it possible to synthetically identify the main patterns of trade and value generation at the global level. It also provides the necessary inputs so that, based on the above, it is possible to differentiate the industrial and trade policies of the countries that gave rise to that specific pattern.

In this study, graph theory complements that of Global Value Chains in the following aspects. First, it makes it possible to obtain a synthetic perspective in the medium term of the change in the commercial leadership of countries with a relatively important aerospace sector. It not only helps observe the size of the sector in terms of the trade volume of each country but also the situation of the trade balance (whether it is in deficit or surplus) and thus the strategy followed by each country in terms of the global chain. It also displays the direction of national trade flows incorporated as nodes. The advantage of performing the exercise for several years is that it makes it possible to analyze the change observed in the position of each country as a result of the strategy followed, either by aligning with the upgrading strategy in the GVC or, as in the case of Canada and China, with diametrically different strategies. This section describes the graph or network methodology.

In recent decades, the application of network theory in the social sciences has become important because it can analyze relationships and interdependencies between data sets, such as countries, individuals, companies, economic sectors, and semantic fields. Network analysis in economic science has been little explored. However, in recent years, it has had an important boom because this type of qualitative analysis makes it possible to visualize, in a simple way, complex structures, such as the institutional and functional design of a sector or an economy. In the analysis of a network, the structure of relationships in which each actor (node) is involved is considered. These actors or nodes are described through their connections, which are visualized according to their relevance if they are relevant to the nodes' structure (Salomé, 2003).

Thus, network or graph analysis focuses on the relationships between entities and not on the entities themselves. Synthetically, a network is a set of points connected by links (lines or edges) or an association rule that indicates how the nodes are related (Mitchell, 2009).

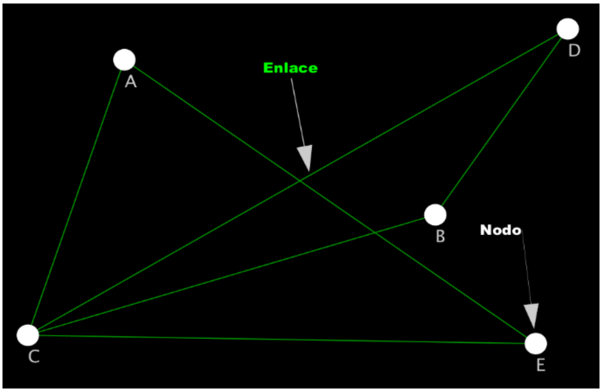

Figure 1. General network diagram.
Source: created by the author based on Mitchell, 2009.

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A network can be denoted in the standard way as follows:

$$G = (N, E) \tag{1}$$

Where N is the set of nodes and E is the set of links. Therefore, Figure 1 is composed of 5 nodes and 6 links, which can be expressed as:

$$N = \{A, B, C, D, E\} \tag{2}$$

$$E = \{(A, C), (B, C), (C, D), (C, E), (D, B), (E, A)\} \tag{3}$$

An alternative way to represent the relationship described in the network of Figure 1 is with a matrix W known as adjacency matrix or binary matrix. This matrix W represents nodes in rows and columns. If element i is linked to element j then elements w_{ij} and w_{ji} will have the value of 1. Otherwise, if the link is non-existent, the matrix component will have a value of zero. The above has the immediate implication that the adjacency matrix is symmetric; it has the same number of rows as columns.

$$W_{ij} = \begin{Bmatrix} 1, \text{if i, j are linked} \\ 0, \text{if i, j are not linked} \end{Bmatrix} \tag{4}$$

$$i, j = 1, \dots, n$$

$$W = \begin{bmatrix} 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \end{bmatrix} \tag{5}$$

$$W_{ij} = W_{ji} \tag{6}$$

A different type of network analysis can be established using weighted networks or weighted graphs. This type of analysis presents the links in a valued or weighted manner (Newman, 2018). These links are associated with intensity, represented by a numerical value. The greater the intensity of the association, the greater the representation, measured in width of the link between the nodes. Figure 2 represents the above.

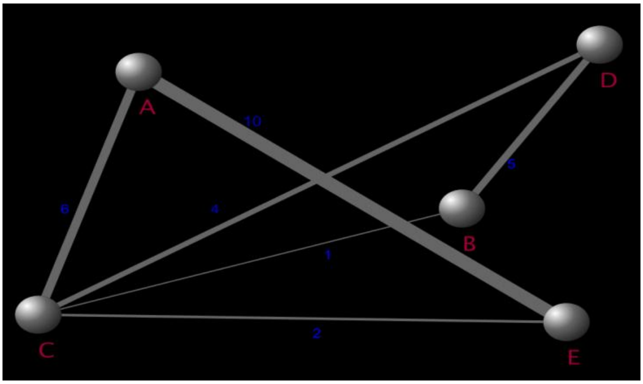

Figure 2. Representation of nodes and links
Source: created by the author based on Mitchell, 2009.

The thickness of the links in Figure 2 illustrates the intensity of the relationship between two nodes. The matrix representation of the network above is:

$$Z = \begin{bmatrix} 0 & 0 & 6 & 0 & 10 \\ 0 & 0 & 1 & 5 & 0 \\ 6 & 1 & 0 & 4 & 2 \\ 0 & 5 & 4 & 0 & 0 \\ 10 & 0 & 2 & 0 & 0 \end{bmatrix}$$

(7)

To find the importance that the node has compared to others, the volume of association is calculated from the number of links; this calculation is known as degree centrality. This is the simplest measure, and it measures the number of connections that a node has with other nodes. The node that has the most neighbors is known as the “hub.” Degree centrality is a local and static indicator, which only considers the direct neighbors of a node.

Thus, to establish the degree centrality measure, this study calculates the adjacency matrix shown in equation 8 (Wasserman & Faust, 1994).

$$D_c = \sum_{j=1}^{n} x_{ij} = \sum_{i=1}^{n} x_{ji}$$

(8)

The aerospace industry in the world

From 1995 to 2017, global trade in Aerospace Industry (AI) goods and services has grown at average rates of 6.7%. Airbus (2017) estimates that in the next 20 years, the number of existing aircraft will reach double the current number due to flight demand and trade growth. However, this production will also tend to have more technology that represents greater added value, such as, for example, that linked to information and communication technologies (ICT), location, security, and entertainment services.

How these countries and firms position themselves to meet this growth will determine the shape of future global aerospace production and the distribution of the benefits derived from it.

Currently, five countries account for 82% of aerospace production and 85% of world trade flows (USA, Germany, China, France, and the UK). When considering the origin of the companies, which generally carry out their production processes outside their territory, locating in countries or regions that offer cost advantages, the concentration becomes even more dramatic.

The production of the largest companies in the aerospace industry does not occur in a single location but is integrated with the production of parts from different origins. The phases of the production process, distribution, and forward linkages, such as research and development, design, production, assembly, marketing, and others, are as varied as the places where each of them takes place. For this reason, their production is defined in the form of global chains.

The global aerospace value chain is made up of large manufacturers. These manufacturers are called OEMs (Original Equipment Manufacturers) and may or may not manufacture intermediate goods. However, they always sell final products, such as engines, airplanes, satellites, and helicopters (Ministry of Economy, 2017). A second element of the production chain is the manufacturers of goods and components that go directly to the final assembly line, such as wings, fuselages, landing gear, harnesses, and seats, among others. This is known as Tier 1. The next level is called Tier 2, the companies that supply parts that will be integrated into Tier 1, such as connectors, insulators, cables, composite materials, laminates, switches, and others.

Given the concentration of production, trade, and the origin of the leading companies in the sector, the opportunities for emerging countries seem to be few. In the best of cases, they integrate into the production chain as Tier 1 or Tier 2 companies, segments with much lower added value generation.

As mentioned above, education and training linked to AI are developed to meet the needs of integration in the chain. They are limited to serving the needs of leading companies in specific technical requirements and certifications. The benefits along the aerospace production chain are distributed as follows:

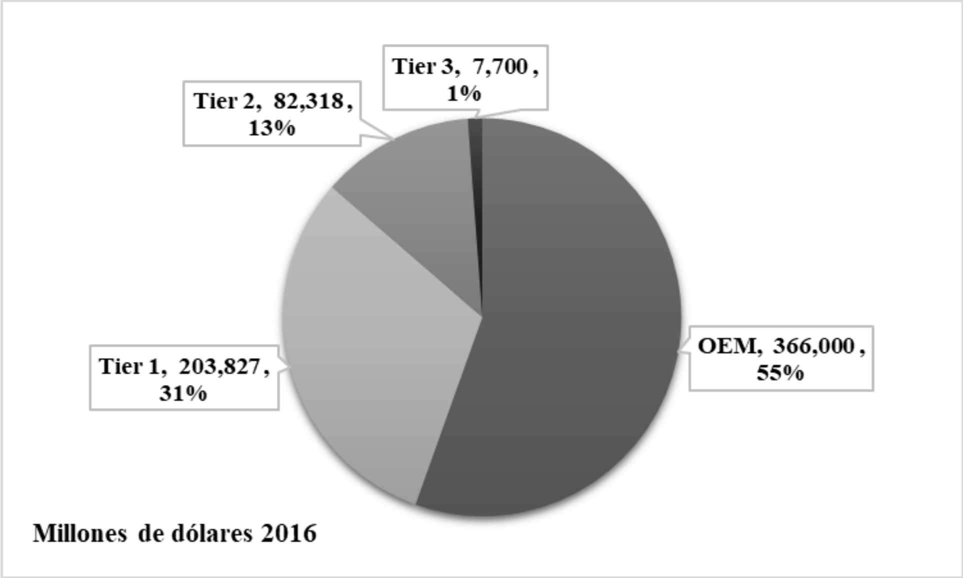

Figure 3. Distribution of benefits in the AI chain, 2016.
Source: created by the author with data from Deloitte (2018).

The OEM segment is the one that represents the highest profits in the chain. If it is considered that Tier 1 companies are generally also located in developed countries, it is possible to state that these absorb more than 74% of the profits of the global production chain. In this area, the United States represents—in terms of regions, if compared to Europe—better performance in key indicators (revenues, operating margins, return on investment, and others) (Deloitte, 2018). As will be argued below, the growth prospects of the industry are positive because it is necessary to replace an important part of the current fleet and to meet the growth in world demand. In a scenario of industry growth, the distribution of the benefits associated with growth will depend on the complex interaction of internal and external factors. These factors include the development of capabilities by domestic companies, supported by industrial policy, not to integrate into the chain in the long term but to create companies that compete in each industry segment. With this goal in mind, China has been able to combine industrial policy with the development of endogenous capabilities and financing to take the lead (Deloitte, 2018). In this field, Mexico has not developed the endogenous capabilities that would make it possible for it to enter as a new producer in the aerospace chain (Brown et al., 2013), nor does it have an industrial policy in this area that points in that direction. Moreover, its strategy has been limited to the supply of components to meet the needs of the leader of the value chain (Flores et al., 2017). This contrasts with what has happened in countries such as Brazil, which have built national industries and companies financed by public spending.

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Mergers and acquisitions within AI, although relevant, are not the dominant strategy. In the coming years, the major companies' expansion strategy will be 70% through organic investments in strategic cooperation (KPMG International, 2016).

Having outlined the general trends of AI globally, this section describes aerospace production and trade patterns over the last 24 years. The section emphasizes industrial and trade policies that led to changes in these patterns during the period under study. The above, in principle, makes possible not only the dimensioning of the sector in the world but also the analysis of Mexico's position in this context.

Aerospace trade outlook in the world

One of the most significant factors in explaining the growth in demand for flights worldwide is per capita income. Generally, to the extent that personal income increases, the consumption of goods and services also increases. Therefore, a shift in the aerospace industry's demand curve can be observed, derived mainly from the increase in the movement of goods and people. As a result, it is possible to observe a positive correlation between the increase in per capita income and the number of flights per capita. Figure 4 illustrates this correlation for 120 countries in 2017. The data indicate that when the per capita income of one country is 10% higher relative to another, the number of flights per capita is 0.4% higher.

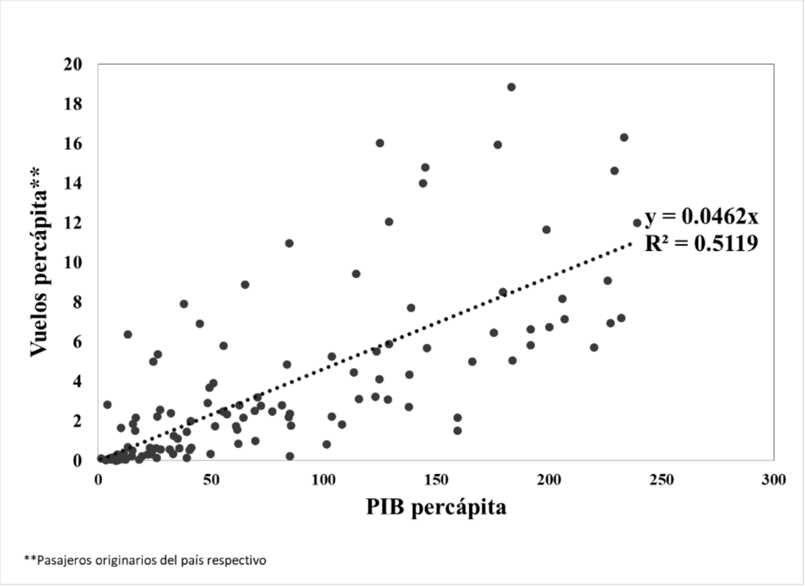

Figure 4. Correlation between revenue and flights.
Source: created by the author with data from the Global Market Forecast, 2018, AirBUS.

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Per capita income is not the only factor explaining the growth in the number of flights. Another factor is the increase in intra- and inter-regional trade, particularly from emerging countries. Thus, according to Airbus (2018), the importance of trade from 54 emerging economies, which together will account for 60% of global economic growth in the next 20 years, is a key driver of future air traffic growth.

According to AirBus (2018), the growth of the middle class is another relevant factor in explaining the expected increase in air traffic and, consequently, the growth in the number of aircraft required. The reason for the above is that this income segment regularly travels, either for vacations within their regions or business reasons. Table 1 shows the expected growth of the middle class globally, measured in millions of households.

Table 1
Projected growth of the middle class in the world, 2017-2037

Global Middle Class Households with annual income between $20,000 and $150,000 (constant 2017 PPP prices)			
Region	2017	2027	2037
Africa	216.	347.	527.
Asia-Pacific	1406.	2071.	2811.
CIS	113.	160.	189.
Europe	454.	476.	479.
Latin America	348.	437.	520.
Middle East	187.	231.	259.
North America	260.	264.	264.
Middle-Class Total	2984.	3986.	5049.
Population Total	7550.	8330.	9010.
Middle-Class %	40%	48%	56%

Source: Oxford Economics, Airbus

The estimation is that the number of flights and the number of airplanes needed to satisfy the growing demand will increase. Other factors will increase air traffic in the future, such as the number of megacities worldwide. The existence of a megacity implies a much higher number of international and local travelers compared to other cities. The factors that explain this are mainly the growth of international business centers, tourist attraction centers, and greater commercial and financial flows, among others. Table 1 displays the projected number of megacities in the world in the next 20 years. Megacities are defined as cities with more than 10,000 daily passengers arriving in the city for the different reasons mentioned above from a distance of more than 2,000 miles[2].

[2] By this definition, it is expected that by 2032 Mexico will have only one megacity, Mexico City; by 2037, Cancun is expected to reach that size and become the second largest megacity in the country.

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Table 2
Projected growth of megacities in the world

Number of megacities in the world * YEAR				
2017	2022	2027	2032	2037
64	70	76	84	91

* Cities with more than 10,000 long-haul passengers per day (flight distance > 2,000 miles excluding domestic traffic)

Source: Global Market Forecast 2018, Airbus

The above data are a sample of the reasons that underpin a significant growth outlook for the aerospace industry worldwide in the coming years. The development of growth strategies by aerospace companies worldwide, in conjunction with the specific type of trade policies and development of endogenous and innovative capabilities formulated at the country level, will determine global aerospace trade patterns and the distribution of value generated by the industry. The following section describes aerospace trade patterns over the last two decades.

World aerospace trade, 1995-2017

Figure 5 illustrates aerospace trade patterns in 1995 using graph theory. The thickness of the links indicates the size of the trade flow, measured in millions of dollars. The direction of the vector indicates the direction of exports and the recipient of that flow in imports. To show the importance of each country in world trade, the size of the sphere shows the trade balance in absolute terms (exports + imports) while the color is an indicator of the balance; if it is green, it is in surplus, if it is red, it is a deficit.

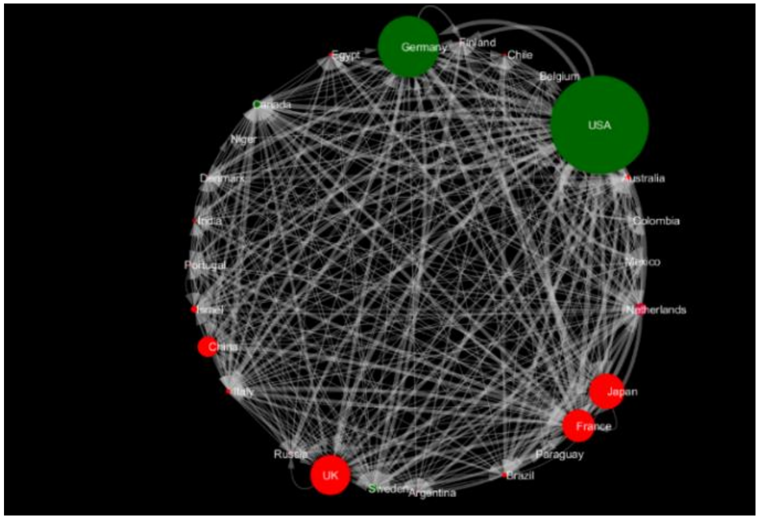

Figure 5. Trade and world economic transactions balance in the aerospace industry, 1995.
Source: created by the author with data from UNCTAD STAT, 2018.

The figure above illustrates that the United States was the world leader, with a trading volume 2.5 times greater than its closest competitor, Germany. One of the patterns that stand out is that both countries are the world exporters of value-added. In other words, the aerospace industry was concentrated in these two countries.

Japan, France, and the United Kingdom are far behind and in deficit in aerospace trade globally, followed by China, with a trading volume fifteen times lower than that of the United States. For its part, Mexico for that year does not appear on the international scene. Mexico exported 316 million dollars, equivalent to 0.5% of the world aerospace trade volume, with a share equivalent to 0.5% of the world trade in the industry. The United States accounted for 99.1% of its exports that year.

Figure 6 shows an illustration of the aerospace trade in 2005. As can be seen, there are changes of the highest relevance compared to the trade patterns existing in 1995. First, Germany grows at practically the same trade volume as the United States, with the difference that the former continues with a surplus pattern. At the same time, the US goes from a surplus to a deficit. Canada has become a major player, occupying third place in trade volume and with a surplus.

Meanwhile, the United Kingdom and France lost their share in world trade. China began to become a significant player, surpassing France, although with a deficit. At the Latin American level, Brazil, through a strategy of creating local companies supported by public resources, is the most significant player in the region.

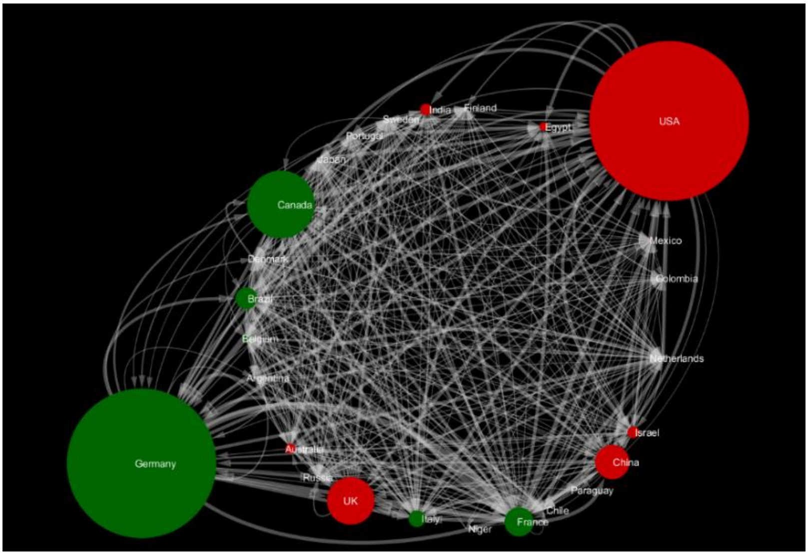

Figure 6. Balance of trade and global economic transactions of the aerospace industry, 2005.
Source: created by the author with data from UNCTAD STAT, 2018.

Mexico diversified its export destinations, expanding its commercial networks from 11 countries in 1995 to 17 in 2005. This generated marginally lower relative sales to the United States, to which it exported 95.8% of its total aerospace exports that year. However, its foreign sales volume fell from 316 to 290 million dollars, a drop of 8% in the trade volume of the sector compared to 1995. Taking into account that world trade grew by 20%, the Mexican share of world trade fell from 0.5% to 0.39%.

By 2017, the aerospace trade had grown 128% since 2005, occasioning a significant re-composition of the AI international trade structure. The United States once again established itself as the commercial superpower of the world, albeit resulting from establishing companies in other countries and using the cost advantages generated from relocating to other regions that make it run a deficit. Germany continued to be in second place in trade volume, with a constant surplus, reflecting a different production strategy, in which the phases of high-value generation (research, design, and system components) are produced internally.

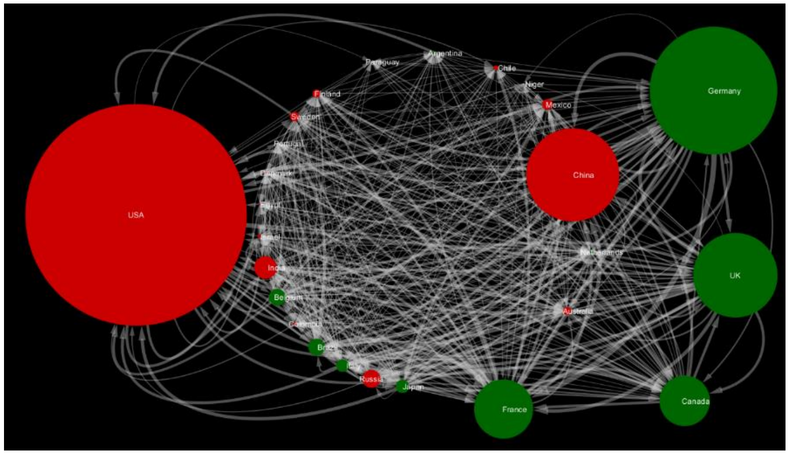

Figure 7. Balance of trade and global economic transactions of the aerospace industry, 2017.
Source: created by the author with data from UNCTAD STAT, 2018.

The economic growth of China is reflected in its aerospace trade volume. In 2017 it became the third-largest trading power in the industry, albeit with imports exceeding its foreign sales volume. The above is the result of the industrial policy of China, as well as financing (which generally comes from its state-owned banks) and the development of endogenous capabilities that made it possible for the country to build companies capable not only of integrating into a chain but also of competing with the leading companies in each segment. The United Kingdom, France, and Canada, respectively, are the countries that rank after those mentioned above as the major producers and traders of aerospace goods and services.

The volume traded by Mexico also grew significantly (157% in relation to 2005), a growth higher than that of the world, which made possible the growth in the Mexican share of world trade. Furthermore, trade destinations are diversified, going from having seventeen trading partners in 2005 to twenty-three in 2017. However, despite ranking as the twelfth aerospace producer worldwide, Mexico's participation in the GVC and world aerospace trade continues to be marginal, as it was throughout the period analyzed. The participation in the world AI trade of Mexico was 0.5% in 1995, 0.39% in 2005, and 0.44% in 2017.

The low participation of Mexico in global AI is a consequence of its integration strategy into the GVC, starting with the production of assembly segments that represent the lowest value generation and trying to upgrade the production chain. A clear example of the impossibility of upgrading the value chain with a technological upgrading strategy like that followed by Mexico is that, despite specific efforts to develop aeronautical components with high Mexican content, the generation of high value is protected by property rights and even by access to knowledge of specific processes in each country. Consider the case of Bombardier Aerospace in Queretaro with the construction of the Learjet 85. The plant located in Mexico is in charge of manufacturing the fuselage, assembling the wings, the horizontal and vertical stabilizers, and manufacturing and installing the electrical harnesses (ProMéxico, 2014). However, research and design are performed outside Mexico (mainly in Canada and Europe) and final assembly in Wichita, USA.

Beyond the specific positions held by each of the countries, it is important to highlight the trade and industrial development policies that have generated the changes analyzed so far, particularly in those countries where the changes have been most significant.

The strategy followed by European firms, supported by their governments' trade policies, was to relocate their companies to areas that offered cost advantages. At this point, the boom in information technologies provided the technological basis for productive decentralization. Thus, to supply the North American market, some European companies established themselves in places that allowed them to obtain cost advantages, both in terms of production and distribution to the places of assembly or final consumption. Lower labor costs, trade agreements, and Mexico's geographical proximity to the US positioned it as a destination for AI investments to supply the North American market, albeit in specific and relatively low value-added products.

China went from being a low aerospace production and trade country in 1995 to a powerhouse in 2017, with a diametrically different strategy. China started attracting aerospace investments in the early 1990s, offering tax incentives and a highly skilled workforce. Unlike that of countries such as Mexico, the Chinese strategy was not to insert itself in the long term into a global value chain led by countries that are already producers but to develop endogenous capabilities through the use of targeted industrial policies. They created access to financing—initially mostly public and later with public-private partnerships—to carry out the entire process of the chain, from research to development, design, production, assembly, and marketing of the final AI goods. One of the tangible results is that the Chinese industry designs, develops, and produces aircraft and recently built the Formosat-5, the first satellite developed entirely by the Republic of China.

On the other hand, North American and Canadian producers, seeking cost advantages, have taken a chance because their OEMs no longer integrate all the activities of the value chain of the sector around headquarters within their territory. However, they entrust those activities to Tier 1 suppliers through contracts with very tight technical specifications in other territories (Economic and Commercial Office of the Embassy of Spain in Ottawa, 2018).

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Conclusions

This study analyzes the changes in global AI during the last 24 years and the national policies that generated them through a theoretical approach of GVC and graph theory. These changes are caused by adjustments in trade relations associated with each country's comparative and competitive advantages. These relations were replaced by inter- and intra-firm relations with a high level of interdependence. The trade of intermediate goods and global exchange is organized in the form of value chains. The great explosion of information and communication technologies provided the technological basis for the promotion of these changes.

In this sense, the aerospace industry is integrated as global production chains, with countries that constitute the production center. Within these countries, the most value-generating stages of the chain are developed. These chains are protected by regulations on property rights, certifications, and process standardization, and satellite countries that perform, to a greater or lesser extent, Tier 1 or Tier 2 functions (as is the case of Mexico). In this context, developing countries seek to integrate into these productive activities by generating domestic growth through integration into value chains under the assumption that such integration produces positive spillovers. These positive spillovers are produced by learning and creating endogenous capabilities that will make it possible for countries to gradually move up the value chain toward more profitable activities.

The study gathers evidence related to the fact that this strategy is limited from the outset and that public policy actions based on the upgrading model deepen asymmetries and increase the subordination of non-leading companies and countries through standardized process requirements. It produces relative changes in the leadership of the main players at the country level but does not allow the entry of new competitors.

A different case is China, which went from being a low aerospace production and trade country in 1995 to a powerhouse in 2017, following an AI growth model diametrically different from integration into GVCs in a traditional way. The Chinese integration method was through the development of endogenous capabilities not aligned to international firms' requirements. They completed the strategy with the use of targeted industrial policies and access to financing, mainly from State banks, to carry out the complete process of the chain, from research to development, design, production, assembly, and marketing of the final goods of AI.

The study presents evidence that the countries that followed a GVC integration strategy seeking growth in the chain with an upgrading strategy have maintained marginal shares in both production and world trade volume. Such is the case of Mexico, whose share of world aerospace trade was 0.5% in 1995, 0.39% in 2005, and 0.44% in 2017.

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The above is just a hint that the strategy to move up the chain toward more profitable and value-generating activities should be different from traditional upgrading. The strategy followed by Mexico to join the AI GVC, together with the lack of an industrial policy and comprehensive development of endogenous capacities, has kept the country in the low-value segments of the chain, a fact that is reflected in the practically zero participation of Mexico in international trade.

From a broader perspective, Mexico's competitive strategy is based on low salaries for the sector (average AI salaries are approximately 8,000 pesos per month). These salaries are complemented by a non-existent industrial policy for the sector and low investment for the development of endogenous capabilities to understand the complete aircraft production cycle. Institutional education systems are designed to meet specific technical production requirements of transnational companies, and in most cases, remain at low levels of specialization. Forty-seven percent of the teaching programs corresponds to the levels of Bachelor Technician, Basic Technician, and Higher University Technician, while only 1% corresponds to a master’s degree program (ProMéxico, 2014). The above demonstrates that specialization is not generated in the higher segments of knowledge creation, which hinders innovation.

Although Mexico and China have wide demographic, economic, territorial, and resource access differences, some general lessons from the Chinese industrial policy could be learned by Mexico. In principle, the very design of an industrial policy that privileges key sectors for the economy cannot be avoided by Mexico, as it has been for the last 30 years. Although it is complicated for the financing of this policy to come from the banking sector (as in China's case with the State-owned banks), it is necessary to allocate part of the public resources to the development of technologically advanced sectors. This would be unthinkable without greater resources to finance this type of policy.

Moreover, it is necessary to develop an educational branch for the aerospace sector to meet the local and short-term needs of multinational companies located in Mexico and cover larger and more elaborate stages of the AI production process gradually and steadily, as in the case of China.

The above should be accompanied by a competition policy not based on low wage costs, but in the opposite direction, which would make the incorporation of skilled labor into the aerospace sector more attractive, closely accompanying the sector's relatively high productivity.

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