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Spatial Co-location Patterns of Aerospace Industry Firms in Mexico

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Abstract The Aerospace Industry (AI) is considered strategic in Mexico due to the opportunities it offers Mexican business communities to insert themselves into a global value chain of high competitive standards. Due to its production specificities, it needs to develop a chain of suppliers that may lead to externalities or intentional knowledge transfer and the creation of networks with local economies and business co-locations. This paper aims to investigate patterns of co-location of firms and establishments around the AI across Mexico. The analysis applies spatial statistical techniques to detect spatial agglomerations of different industrial sectors related to the AI. The findings include a detailed description of the spatial distribution of AI co-location patterns in terms of industrial branch and firm size. Results indicate that the AI industry is mainly spatially co-located by itself and by industries in the electronics, machinery and equipment sectors. Our findings could potentially provide input to policy makers in terms of clustering and public policies according to regionally productive vocations.

Keywords Co-location · Aerospace industry · CLQ · Spatial statistics

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Introduction

The Aerospace Industry (AI) in Mexico has attracted the interest of scholars and public policy makers because of the opportunity it offers Mexican business communities to improve their competitive advantage over those belonging to its supplier chain, which is internationally recognized for having high quality standards (Casalet et al. 2011). National and local governments consider the AI as strategic due to its potential contribution to technological progress through its development of high value-added productive processes and because of its high probability of knowledge spillover through its links with local economies (Lublinski 2003; Beaudry 2001). It may also influence the ability of local firms to make manufacturing more efficient and to develop activities with a higher degree of specialization, which is essential for host developing economies that hope to benefit in the long run from foreign direct investment (FDI) (Humphrey and Schmitz 2002; Keesing and Lall 1992; Piore and Ruiz Durán 1998; Schmitz and Knorringa 2000; UNCTAD 2011).

A firm's location is important and has implications not only for the firm, but also for the region in which it is located (Bunyaratavej et al. 2008). A suitable location can reduce transportation costs and provide better accessibility. Proximity to other firms could involve the sharing of similar cultural and institutional goals and promote technological transfer (Humphrey and Schmitz 2002; Williamson 1979; Batheld et al. 2004). Co-location of diverse productive sectors around the AI is a characteristic of mature aerospace clusters usually composed of metallurgy, machinery and equipment, electronics, automotive and materials manufacturers (Chu et al. 2010).

Company size affects the flexibility of the supply chain (Martínez and Pérez 2005). In this regard, clusters of industries – for example, automotive, aerospace, and electronics – are typically anchored to an assembly company that operates as the leader and is characterized by its technological and design capabilities (Giuliani et al. 2005). Specifically, larger aerospace clusters, such as one in Montreal, are comprised of one or several Original Equipment Manufacturers (OEMs) surrounded by several small and medium enterprises (SMEs) that supply components and parts and are located at different tiers in the supply chain (Niosi and Zhegu 2005). In this context, it is interesting to identify the structure of the different AI clusters in Mexico and differentiate business co-location based not only on industry, but also on the size of the economic unit involved.

This study investigates co-location patterns of establishments around the AI based on their geographical location. Specifically, our study exploits geo-referenced data of economic units belonging to this sector. Given the characteristics of this data, each observation presents an attribute that allows its categorization in terms of the industrial sector and firm size. Our aim is to answer the following research questions: To what extent do firms in different industrial sectors tend to be spatially co-located around Aerospace Industry firms? If they do, are those sectors showing higher chances of being spatially co-located? And finally, what specific industries may be more susceptible to the effects of inter-sectorial upgrading due to their proximity to the aerospace industry?

To meet our research objectives, we use a spatial statistics measure called Co-location Quotient (CLQ) (Leslie and Kronenfeld 2011) from which it is possible to explore proximity patterns between two particular industrial branches that might differ in terms of location and employment size. The results obtained allow us to look at the co-location directionality of each pair of industrial industries that consequently are visually displayed in a fairly similar network diagram.

Our contribution to the extant literature is threefold. First, this appears to be the first study that combines the use of geocoded information with the application of spatial statistics techniques in the context of a relevant industrial sector in Mexico such as the AI. Second, we provide a new way to display the results via a network diagram, which in turn facilitates the visualization and description of the findings. Third, the analysis of co-location differentiated by company size is a novel way to identify the specific structure – not only by industry, but also by the size of the economic unit – of aerospace clusters located in Mexico.

A Brief History of the Aerospace Industry in Mexico

The presence of this industry in Mexico dates back to before the Second World War (Jiménez 2013), although the installation of the first foreign firms occurred at the time of the "import substitution model", an economic policy that advocates replacing foreign imports with domestic production to enhance the vertical integration of the economy (Alarcon and Mckinley 1992). In the 1960s, companies such as Rockwell Collins and Light Switch arrived in Baja California (Carrillo and Hualde 2013). Others dedicated to the maintenance of parts and the manufacture of aircraft parts were installed in Querétaro (Villavicencio et al. 2013), and in 1999 the design centers of General Electric (GE) and the Sonora Smith West (Contreras and Bracamonte 2013) were also located in the state. By 2000, and according to the Ministry of Economy (SE), 20 companies in Mexico were together exporting approximately USD $150 million worth of aircraft parts.

Due to the characteristics of the sector and its contribution to Mexican employment, investment and exports, in 2003 the Secretaría de Economía (SE) announced the interest of the federal government in developing the AI sector by attracting leading international companies (Secretaría de Economía (SE) 2013). The main interest was to foster industrial clusters capable of promoting the competitiveness of the national business and of local universities and public research centers (Casalet et al. 2011). As of 2013, the AI consists of approximately 259 firms that provide more than 34,000 jobs in 18 entities, mainly in central and northern Mexico (ProMéxico 2013a, b). Five of these States stand out as constituting 76 % of the sector's total number of firms: Baja California, Sonora, Querétaro, Chihuahua and Nuevo León. Official records have identified them as the most important "regions" for the Mexican AI, whose capabilities, specificity and existing industrial niches enable them to develop strategies that orient their potential productive vocations, see Fig. 1.

Theoretical Justification

By building on the New Economic Geography (NEG), it is possible to understand the firm's location choice and the structure it acquires. Agglomeration economies are considered as the main scenario where social and technological innovations develop,

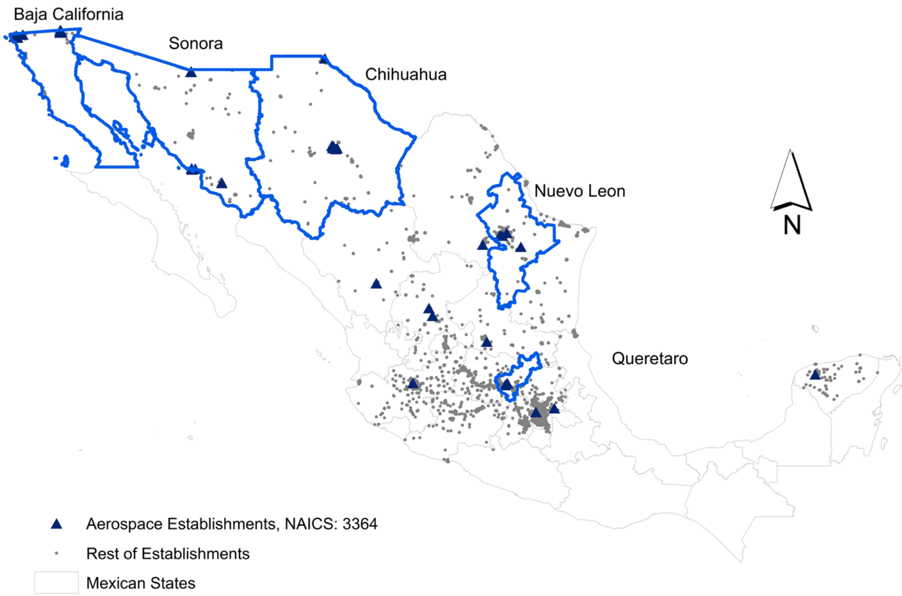

Fig. 1 Spatial distribution of the aerospace industry in Mexico

mainly through the establishment of business linkages (Fujita and Thisse 1996). These agglomerations are suitable spaces to promote spillovers given that they facilitate information exchange between firms and intensify communication and information transfer based on personal contact between the diverse actors involved in the process (Marshall 1920; Batheld et al. 2004). These benefits can increase when agglomerations include actors with international affiliations, given that the information and skills they acquire tend to disperse within the agglomeration. Once they become integrated into firms in related sectors, they influence the ability of these firms to generate information and execute effective labor divisions (Batheld et al. 2004).

The externalities originated through the process, either technological (spillovers) or pecuniary, are key determinants for explaining business linkages at different geographical distances. These, in turn, allow for the integration of firms from AI-related sectors, which implies a horizontal movement toward a new sector that requires the implementation of productive activities not previously carried out. It involves a process of technological transfer executed beforehand and customer-supplier links between and among businesses, resulting in a horizontal upgrading of the firms involved. Once integrated into the industry, these firms may upgrade their products, processes or functions (Humphrey and Schmitz 2000). In this context, some argue that, once they adapt new production technologies, firms may evolve to undertake more complex activities related to the manufacture of parts and sub-assembly for the aerospace industry. This may eventually lead to the abandonment of basic activities such as tooling or tool machining (Esposito and Passaro 1997).

Horizontal upgrading might also involve the development of suppliers through a cooperative relationship established between client and supplier within a given GVC. Its purpose is to generate permanent improvements in the suppliers' performance while at the same time strengthening the competitive advantage of clients (Hahn et al. 1990;

Krause 1997, 1999; Vickery et al. 2003). For this reason, it can be considered a long-term competitive strategy (Giunipero 1990; Monczka et al. 1993; Hartley and Choi 1996; Goffin et al. 2006) that benefits multinational corporations by reducing their production costs and delivery times for certain products, thus rendering them more competitive. (Dyer 1996; Li et al. 2007; Blalock and Gertler 2008), Not only that: local businesses can also benefit, assuming there is a transference and integration of technological development into their productive capacities, in addition to different agents that may become involved in the process (such as universities, research centers and industrial associations) (Padilla-Pérez 2008).

In this context, the role of some local and federal policies has been relevant in the promotion of aerospace spatial clustering within the country. According to Casalet (2013) these policies have involved: a) the attraction of world-leading firms in the sector, b) implementation of fiscal incentives, and c) promotion of locating anchor firms within industrial parks. Therefore, this paper acknowledges the increasing interest in the AI sector, focusing on the spatial distribution of those firms that belong to it.

Methods and Data Description

In recent years, an increasing number of empirical studies, including those of Duranton and Overman (REStud, 2002), Ellison and Glaeser (JPE, 1997), Mori and Smith (2011), and Billings and Johnson (2014), have been devoted to describing industrial agglomeration patterns using point-based firm-level data.

Although widely used, some characteristics of the Ellison and Glaeser (1997) (E-G) index prevent us from applying it to the present analysis. First, the calculation involves shares of a particular industry in a determined area, the share of total employment in that area, and the sizes of the plants comprising that industry. Given that the data used in the analysis does not contain information about the exact number of employees but, rather, a range of employees, the replication of such an index is difficult. Furthermore, the E-G index uses geographical units, such as states or counties, as the distance criteria or scale upon which to measure industrial agglomeration. It is now well understood that such an index is affected by the underlying spatial zoning system, i.e., the shape, size and relative position of spatial units. This has been labeled Modifiable Areal Unit Problems (MAUP) in the regional science literature (Barlet et al. 2013; 338).

Another approach to describing industrial location patterns helps overcome discreteness, as it considers space as continuous. A well-known index proposed by Duranton and Overman (2002) consists of taking the density distribution of bilateral distances between all pairs of plants in a given industry. The test involves localization of industries based on whether the density distribution of bilateral distances is close to the density distribution that would be expected if plants were randomly allocated in space. In a somewhat similar setting, Marcon and Puech (2003) also develop an index aimed at assessing spatial localization of point patterns. While the core strength of these two continuous measurements are independent of the spatial unit size choice, the practical implementation may involve computationally intensive procedures (Kominers 2008; pp. 8). Although we recognize the importance of developing these types of measurements, this area is left for further research.

We emphasize that the main interest of this study is not in exploring agglomeration patterns per se, but instead, co-location patterns of industries in relation to the aerospace industry. The method used here, the CLQ statistic, is consistent with our objectives because it allows the exploration of proximity patterns between two particular industrial branches that might differ in terms of their location and employment size. It is particularly useful for two reasons. First, while a symmetric representation of the results is obtained – meaning that for every pair of categories (industries), the corresponding CLQ is calculated through a *nxn* matrix – the off-diagonal results of such a matrix might not be symmetric. In other words, while industry A might be co-located to B, the inverse is not necessarily true. Second, we take advantage of this directionality of each pair of industries, and consequently the relation between them is visually displayed in a fairly similar network diagram. This facilitates the exposition of the findings, given that exploring co-location patterns by firm size is a crucial component of the present analysis.

The CLQ is specifically defined with respect to two categories (for example, types A and B) and provides a measure of the degree to which one categorical subset is spatially dependent on another. That is to say, CLQ $_{A->B}$ measures the degree to which type A events are spatially co-located by type B events. It is calculated as the ratio between the points being observed in comparison with the expected points belonging to a specific type, between the set of closest neighboring points of another type.

The CLQ has its roots in the classical location quotient used by geographers and economists to assess the degree of specialization of a region based on specific industries (Blair 1995; Stimson et al. 2006). It is especially useful when performing population analysis with geo-referenced data that, in turn, can be grouped in different categories with the following characteristics: (a) information is nominal, so that other measures, such as *cross-variogram* (Vallejos 2008), are not applicable; (b) analysis is based on specific and not polygonal information, as established in the *join count statistical* (Cliff and Ord 1981); and (c) when the analysis is centered on one population and not on the comparison between two of them, as formulated in the null *cross-k-function* (Cressie 1991) hypothesis.

The CLQ formal representation is based on a given population P, where each individual is categorized or grouped in one of the k-categories part of an *X* set, assuming $A \varepsilon X$ and $B \varepsilon X$ denote potential categories that belong to *X*. CLQ $_{A->B}$ is defined as the ratio observed between the expected proportions of type B events, between A′s closest neighbors.

$$CLQ_{A \to B} = \frac{C_{A\_B} / N_A}{N'_B / (N-1)} \quad (1)$$

Where N denotes the size of the total population; N_A corresponds to the population size of category A; N'_B denotes the size of population B (if $A \neq B$); and C_{A_B} denotes the recount of type A points whose nearest neighbor is a type B point. A $CLQ_{A->B}$ numerator is the proportion of type B points between A′s closest neighbors (meaning the observed proportion), while the denominator is the proportion of type B points that could be the closest neighbor of type A events (meaning, the expected proportion).

Semantically, CLQ $_{A->B}$ denotes the spatial co-location that A exerts on B, or alternatively, the degree to which B co-locates A. For example, a CLQ $_{A->B}$ close to 2 would indicate that A is twice as likely to have B as its closest neighbor as what might be expected if the location of data in space were randomly distributed. It should be clarified that the co-location expressed by CLQ $_{A->B}$ is unidirectional, since it depends on its relationship to its closest neighboring points. In other words, in the case of observations where A′s nearest neighbor is B, but B′s nearest neighbor is not A, then $C_{A\_B} > C_{B\_A}$; and therefore, $CLQ_{A->B} > CLQ_{B->A,}$ logically expressing that A is more co-located to B than B to A. In a case where the same category or group is analyzed, CLQ is interpreted in a similar way, so that a $CLQ_{A->A} = 0.67$ would indicate that the expectation would be that A is two-thirds as likely to be its own nearest neighbor, given the proportion of A with respect to the analyzed data. In this case, co-location is bi-directional (see Leslie and Kronenfeld 2011, p. 313).

This study uses spatially referenced data available at a firm level obtained from the National Statistical Directory of Economic Units (DENUE in Spanish) prepared by the National Institute of Statistics and Geography (INEGI in Spanish). This database contains more than 4 million economic units (or establishments) located throughout Mexico from the following sectors: manufacturing, trade and services, mining, electricity, water and gas, construction, transportation and storage and financial services.

This source of information includes geographic coordinates (latitude and longitude) for each economic unit, as well as an identifier by entity, municipality and basic geo-statistical area (AGEB). With regard to other attributes, it is also possible to obtain the number of employees based on the following strata: 0–5, 6–10, 11–30, 31–50, 51–100, 101–250 and 251 or more, and the type of economic and industrial activity, based on the North American Industrial Classification System (NAICS) for 2007. As it relates to the present study, the NAICS Code is particularly important because it enables the identification of the industrial branch where establishments belong, given a 4-digit NAICS code.

Results

The analysis first considers 47 NAICS industry codes where the selection was made considering two different sources of information: a) the list of companies in the Matrix of Capabilities, Products and Processes published by ProMéxico (2013a, b), and b) the industry codes that maintain linkages as aerospace industry suppliers (NAICS code: 3364) in the Input–Output Mexican table (2008). (See Table 4 of the Appendix for a full description of each of the NAICS codes considered.)

From the first source (Matrix of Capabilities, Products and Processes) a list of 259 companies is identified which, according to ProMéxico (2013a, b), constitute the Mexican aerospace industry. In order to gather information on their industry classification through NAICS codes, a matching process from the (DENUE) was undertaken. In doing this, it was possible to identify 46 NAICS codes belonging to 259 companies which constitute the Mexican aerospace industry and the associated information that comes from the DENUE. From the second source of information (Input–Output table), it was possible to identify 14 industries that maintain a supplier relationship with the aerospace sector. The final data set is made up of 47 NAICS codes, as only one

(NAICS 4811) was identified in the second but not the first of the sources above described. (See Table 1 for the full list of NAICS codes.) As noted, the wholesale of raw materials for industry (NAICS code: 4342) is of the utmost importance (20 % of units observed), followed by metal structures and products, blacksmith manufacturing (NAICS code: 3323) and the repair and maintenance of electronic equipment and precision equipment (NAICS code: 8112). These three industries together account for almost 50 % of all observations presented in Table 1.

The next step consists of applying the CLQ to identify industries that show co-location patterns with respect to the AI. This test was done for the 47 industries previously identified. In the process, 19 industries (NAICS codes) showed significant colocation patterns, that is, they tend not to be randomly located around the AI. In Table 2 we show the results obtained for each NAICS code, in descending order of the estimated CLQ. Note that it shows all CLQ results with significance,[1] regardless of whether or not they exhibit an estimate greater than the unit. The findings indicate that firms belonging to the AI (NAICS code: 3364) tend to be co-located with themselves, and are mostly related to the production of manufacturing parts.[2] This, in turn, supports the argument that aerospace clusters are often formed by one or several anchor firms surrounded by small and medium-sized firms that supply components and specialized parts (Niosi and Zhegu 2005). The second industry or NAICS code with the greatest CLQ corresponds to internal combustion engines, turbines and transmissions manufacturing (NAICS code: 3336). The rest of the significant CLQ results with a CLQ > 1 corresponds to the following NAICS codes: 3339, 3329, 3344, 3327, 3315, 3262, and 3321.

In order to analyze the co-location of establishments not only belonging to the aerospace industry but also to the industries in the entire dataset, the CLQ is estimated once more and a co-location matrix is generated; see Table 3. As expected, each industry exhibits the strongest co-location index with itself. Among these, machinery and equipment for manufacturing industries (NAICS code: 3332), aerospace equipment manufacturing (NAICS code: 3364), scheduled air transport services (NAICS code: 4811), computer systems design and related services (NAICS code: 5415) and business management services (NAICS code: 5611) are the industries exhibiting the highest-co-location patterns.

Note that aerospace equipment manufacturing is co-located with three different industries: machinery and equipment for manufacturing industries, except metalworking (NAICS code: 3332), internal combustion engines, turbines, transmissions manufacturing (NAICS code: 3336) and with nonferrous metals industries, except aluminum (NAICS code: 3314). Business management services (NAICS code: 5611) is only co-located with scheduled air transport (NAICS code: 5611). Machinery and equipment for manufacturing industries manufacturing, except metalworking (NAICS code: 3332) tend to co-locate with industries of nonferrous metals, except aluminum (NAICS code: 3314) and rubber products manufacturing (NAICS code: 3262).

[1] Significance obtained from Monte Carlo simulations, see Leslie and Kronefeld (2011, pp. 317)

[2] As mentioned above, DENUE's information enables us to gather information relating to firm size. The data suggests a significant presence of micro enterprises (79 %) while aerospace industry (NAICS code: 3364) is dominated by medium-sized enterprises (43 %), that is to say, almost half of the industry is composed of companies which have from 51 to 250 employees.

Table 1 List of industries

Code	Industry / Commodity	Total	%
3149	Other textile product mills	12,458	6 %
3169	Manufacture of other products of leather, fur and substitute materials	1,848	1 %
3255	Paint, coating and adhesive manufacturing	478	0 %
3256	Soap, cleaning compound and Toilet preparation manufacturing	1,044	1 %
3261	Plastic products manufacturing	4,115	2 %
3262	Rubber products manufacturing	877	0 %
3314	Industries of nonferrous metals, except aluminum	131	0 %
3315	Cast molding metal parts	428	0 %
3321	Forged metal products and blanks manufacturing	476	0 %
3323	Metal structures and products blacksmith manufacturing	36,546	19 %
3324	Boilers, tanks and metal containers manufacturing	356	0 %
3327	Metalworking and manufacturing screws	8,148	4 %
3328	Coatings and metal finishing	652	0 %
3329	Other fabricated metal products manufacturing	1,126	1 %
3332	Machinery and equipment for manufacturing industries manufacturing, except metalworking	762	0 %
3333	Machinery and equipment for trade and services manufacturing	148	0 %
3335	Machinery and equipment for the metalworking industry manufacturing	355	0 %
3336	Internal combustion engines, turbines, transmissions manufacturing	50	0 %
3339	Other machinery and equipment for general industry manufacturing	718	0 %
3341	Computers and peripheral equipment manufacturing	111	0 %
3342	Communication equipment manufacturing	151	0 %
3343	Audio and video manufacturing	137	0 %
3344	Electronics Manufacturing	571	0 %
3345	Measuring instruments, control, navigation, and electronic medical equipment manufacturing	212	0 %
3352	Electrical household appliances manufacturing	240	0 %
3353	Generation and distribution of electricity manufacturing	355	0 %
3359	Other electrical equipment and fittings manufacturing	388	0 %
3363	Motor vehicle parts manufacturing	1,221	1 %
3364	Aerospace equipment manufacturing	103	0 %
3379	Mattresses, blinds and curtain rods manufacturing	363	0 %
3391	Non-electronic equipment and disposable supplies for medical, dental and laboratory use, and ophthalmic articles manufacturing	2,179	1 %
3399	Others manufactures	11,691	6 %
4342	Wholesale of raw materials for industry	39,582	20 %
4352	Wholesale of machinery and equipment for industry	2,989	2 %
4354	Wholesale furniture and computer equipment and office equipment, and other machinery and equipment for general use	7,524	4 %
4811	Scheduled air transport	178	0 %
4812	Non-scheduled air transport	107	0 %
4881	Services related to air transport	168	0 %

Table 1 (continued)

Code	Industry / Commodity	Total	%
5413	Architectural, engineering and related activities	5,968	3 %
5414	Professional Design	3,368	2 %
5415	Services computer systems design and related services	2,829	1 %
5416	Management consulting services, scientific and technical	5,798	3 %
5511	Corporate	468	0 %
5611	Business Management Services	2,683	1 %
5615	Travel agencies and reservation services	5,847	3 %
8112	Repair and maintenance of electronic equipment and precision equipment	19,032	10 %
8113	Repair and maintenance of machinery and agricultural, industrial, commercial equipment and services	9,263	5 %
	Number of observations	194,242	100 %

One of the features of the CLQ statistic is that it is possible to obtain uni- or bi- directional spatial co-location patterns. Figure 2 depicts the relationships detected in the above table, where the thickness of the lines shows the strength

Table 2 CLQ results: 19 industries

CLQ	Code	Industry / Commodity
95.626	3364	Aerospace equipment manufacturing
15.102	3336	Internal combustion engines, turbines, transmissions manufacturing
4.515	3339	Other machinery and equipment for general industry manufacturing
4.434	3329	Other fabricated metal products manufacturing
3.894	3344	Electronics Manufacturing
3.522	3327	Metalworking and manufacturing screws
3.224	3315	Cast molding metal parts
2.746	3262	Rubber products manufacturing
2.687	3321	Forged metal products and blanks manufacturing
0.539	3332	Machinery and equipment for manufacturing industries manufacturing, except metalworking
0.495	3169	Manufacture of other products of leather, fur and substitute materials
0.404	4354	Wholesale furniture and computer equipment and office equipment, and other machinery and equipment for general use
0.344	4811	Scheduled air transport
0.334	5611	Business Management Services
0.310	5415	Services computer systems design and related services
0.208	3314	Industries of nonferrous metals, except aluminum
0.182	3324	Boilers, tanks and metal containers manufacturing
0.138	4812	Non-scheduled air transport
0.089	4352	Wholesale of machinery and equipment for industry

Table 3 CLQ results: matrix 19 NAICS codes

Code	3169	3262	3314	3315	3321	3324	3327	3329	3332	3336	3339	3344	3364	4352	4354	4811	4812	5415	5611
3169	2.33		0.78	0.62	0.61	0.52	0.86	0.28	0.66	0.83					0.27	0.18	0.27	0.20	0.40
3262		22.6	1.83	0.34		0.55			3.76		1.84			1.88	0.11		0.41		
3314	0.82	1.87	9.31	0.60	0.61	0.51			2.02	1.61	1.49				0.30	0.05	0.36		
3315	0.60	0.58	0.58	9.60	0.41	0.24	2.07	0.03		0.48	0.57		0.00		0.26	0.10	0.38	0.17	0.16
3321	0.61	0.63	0.60	0.39	4.59	0.77	0.54	0.50	0.17	0.69	0.49	0.60	0.22	0.45	0.62	0.37	0.62	0.05	
3324	0.51	0.50	0.46	0.26	0.82	2.46	0.47	0.28	0.43	0.52	0.56	0.39		0.38	0.69	0.58	0.65	0.35	0.51
3327	0.83			1.93	0.61	0.44	11.3							1.59	0.16		0.35		0.00
3329	0.31			0.12	0.44	0.25		35.4							0.24		0.21	4.07	
3332	0.66		2.24		0.25	0.28			85.4	2.21				2.64	0.09				
3336				0.53	0.68	0.63				12.5			4.44	1.90	0.37		0.38		0.00
3339		2.09		0.54	0.48	0.62					18.2				0.25	0.04	0.21		
3344					0.60	0.41						13.1			0.42	0.25	0.35	0.00	0.00
3364			2.71	0.00					6.06	4.44			182		0.00		0.10		
4352			1.55	0.57	0.70	0.40			4.35	2.11				17.7	0.22	0.00	0.35		
4354	0.27	0.14	0.29	0.26	0.57	0.70	0.21	0.25	0.09	0.47	0.30	0.41	0.23	0.16	6.23			0.11	
4811	0.20		0.05	0.10	0.32	0.60					0.02	0.01		0.00		93.4			13.96
4812	0.28	0.41	0.42	0.32	0.59	0.68	0.31	0.25	0.48	0.37	0.12	0.40	0.00	0.33			6.29	0.37	
5415	0.15			0.17	0.05	0.34						0.00			0.11		0.26	196.0	
5611	0.22			0.32		0.48	0.00					0.00				10.9			135.0

$CLQ_{X\text{->}Y}$: unidirectional co-location relationship of NAICS Code *X* in reference to NAICS Code *Y*

$CLQ_{X\text{->}X}$: unidirectional co-location relationship of NAICS Code *X* in reference to the same NAICS Code (*X*)

$CLQ_{X\text{->}Y} > 2$: more than twice as likely to have sector *Y* as its closest neighbor, that is to say, to be located close by in relation to what could be expected if a location were chosen at random

$0 < CLQ_{X\text{->}Y} < 2$ for example $CLQ_{3364\text{->}4812} = 0.10$: AI only has a 10 % chance of having sector 4812 as its closest neighbor

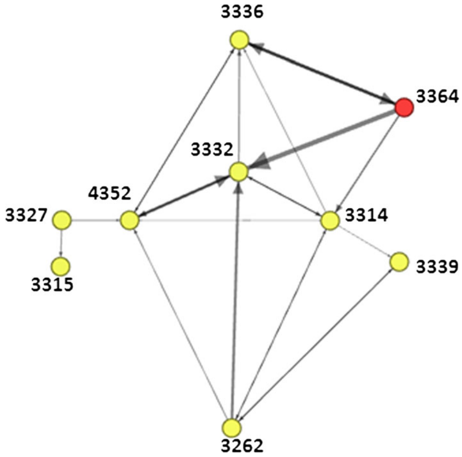

Fig. 2 Directional co-location patterns

of the relationship and arrows show the direction (unidirectional or bidirectional). For example, other fabricated metal products manufacturing (NAICS code: 3329) is co-located unidirectionally with services computer systems design and related services (NAICS code: 5415); and scheduled air transport (NAICS code: 4811) is co-located bidirectionally with business management services (NAICS code: 5611).

We can also observe that aerospace equipment manufacturing (NAICS code: 3364) is co-located with more general industries like internal combustion engines, turbines, transmissions manufacturing (NAICS code: 3336), machinery and equipment for manufacturing industries manufacturing, except metalworking (NAICS code: 3332) and industries of nonferrous metals, except aluminum (NAICS code: 3314), which are bi-directionally co-located. As expected, the first two show a greater relationship with the aerospace industry, but all of them are co-located at the same time with the commercial sector (NAICS code: 4352), which, as we expect, maintains a relationship with almost all the industries in the diagram.

Figure 3 displays results this time by establishment size, where numerical markers have been added to each NAICS industry to differentiate establishment-size groups:

a) micro (0–10 employees): 3364-1,
b) small (11–100 employees) : 3364-2,
c) medium (101–250 employees) : 3364-3,
d) large (251 or more employees): 3364-4,

On the one hand, the figure shows that large-size AI establishments tend to co-locate only with themselves, i.e., not with other size groups of the AI. On the other hand, micro, small and medium enterprises in the AI industry show co-location patterns not only with themselves, but also with other group size establishments in the same industry.

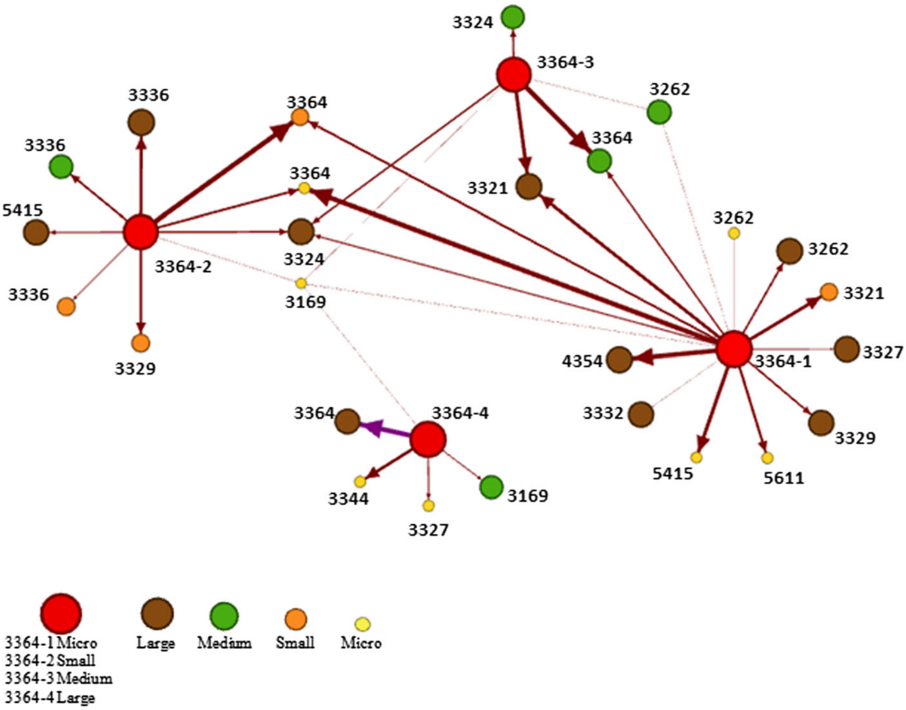

Fig. 3 Directional co-location patterns by establishment size

Note that micro enterprises in the AI exhibit the greatest number of other industrial branches with which they tend to be co-located (approximately 13 industrial branches), while small size establishments co-locate with seven, medium size with five, and large size with only four industrial branches. From the same figure it is possible to identify those industries with which AI establishments tend to be co-located individually; that is, in the case of small businesses in the AI they are most likely to be co-located with small, medium and large establishments in the internal combustion engines, turbines, transmissions manufacturing industry (codes: 3336-2, -3, -4). Medium size establishments in the AI, however, are co-located with establishments of the same size in the boilers, tanks and metal containers manufacturing industry (code: 3324-3). Large establishments in the AI, on the other hand, tend to co-locate as neighbors to microenterprises in the electronics manufacturing industry (code: 3344-1).

Final Discussion

The identification of the aerospace cluster's composition is useful for understanding its location and its relationship to the regional economy. Utilizing the CLQ method, we aimed to provide a better description of the aerospace sector in several aspects, such as its industry composition, industry linkages, and spatial organization. Conclusions can be drawn as follows. First, on the basis of the identification results, it can be concluded that the aerospace industry cluster in Mexico is generally composed of five subgroups: the aerospace industry; metal manufacturing and product manufacturing; the machinery and equipment industry; the electronics industry; and services.

Second, the network of intra-cluster linkages are mainly represented by the links between and among the aerospace industry and other manufacturing sectors like internal combustion engines, turbines and transmissions with a bidirectional co-location. Machinery and equipment, and industries of nonferrous metals are both unidirectional. This means the aerospace industry is especially co-located with these industries. Therefore, the present analysis suggests that the first three industries would potentially obtain upgrading benefits through their relationship with the aerospace industry, while the rest of them (those industries indirectly linked to the aerospace industry) could obtain technological externalities or spillovers more indirectly.

By comparing the results obtained for the aerospace industry in Mexico with the industrial composition of the sector detected for China and the United States conducted by Chu et al. (2010), you can mostly find matches. As compared to China, the Mexican AI industrial composition is very similar, with the exception of the ship and floating devices industry. Regarding the USA, the detected industrial composition is comprised of 38 industries, which largely coincide with those found in the present study, except those relating to communications equipment, agriculture, construction and mining machinery, architectural and structural metal products, basic chemicals, non-apparel textile products, food products, wood products, and HVAC and refrigeration equipment. In general, we can see that this industry is accompanied by the sectors of mechanical engineering, engine manufacturers, parts manufacturers, electrical engineering, cabin manufacturers, support services and maintenance and repairs (Beaudry 2001).

The information obtained from the present analysis therefore points to the likelihood of a productive sector being found non-randomly as the closest neighbor to the AI by identifying patterns of co-location, which facilitates understanding of the industrial configuration of the country's main aerospace agglomeration. These may have arisen due to transportation costs and the availability of human capital, enabling the creation of vertical links between the different actors in the productive sectors identified as their closest neighbors. The benefits to be derived from industrial co-location are related to the exchange of information, which creates a common knowledge base that may perpetuate. These benefits are significant, not only in the private sphere, but also for local economic development; hence their importance and implications for the development of public policy actions. In the aerospace sector, in particular, the co-location of various productive sectors is a feature that signals the maturity level of aeronautical clusters, and therefore the probability of agglomeration economies emerging and bringing benefits to the regional economy.

As we described, upgrading effects may occur in different ways (horizontal, product, process or functional), but, regardless of this, they require certain conditions to occur, such as geographic proximity or clustering between firms; infrastructure; emergence of large firms within the cluster; intellectual and industrial property rights; reliable staff turnover; knowledge generated internally by firms; institutions with knowledge acquired from outside the cluster; public and private funding; international links; and links between the different co-located firms (Humphrey and Schmitz 2002).

This analysis therefore provides input for the design of a clustering policy. However, to deepen the analysis, it should be complemented with an analysis of economic links in the industry (at the national and state levels) by studying the Input–Output Matrix in order to understand the degree of economic integration of the various branches in the industry's production chain. In addition, to broaden understanding of the sector, there is a need for a qualitative analysis to comprehend the dynamics of the industry and the feasibility of domestic producers becoming integrated into this supply chain.

Public policy efforts would advocate the emergence and maintenance of industrial clusters in the regional economy and, at the same time, the appearance of links between enterprises from complementary sectors to facilitate interchange or knowledge and technology transfer through channels such as joint ventures, coproduction partnerships, training, etc. The identification of the aerospace cluster's composition also provides input to develop and design regional-sectorial innovation ecosystems as a regional industrial policy to promote the competitiveness of the regional aerospace industry in Mexico (Cooke 2008).

Finally, it also noted that the aerospace cluster's spatial evolution in Mexico is mainly related to regional product capabilities. The more developed these are, the greater the number of links that the aerospace industry will be able to establish with the regional economy.

The identification of the aerospace industry composition and location is important in pursuing regional policies to promote related variety and principles of smart specialization and forming regional advantages that incorporate the ideas of embeddedness, relatedness, and connectivity (Cooke 2008; McCann and Ortega-Argilés 2013; Boschma 2014). Regional industrial policies or innovation policies that stimulate public and private investment in high technology and knowledge-intensive spinoffs would be recommended in the co-location patterns identified. Too, mechanisms for facilitating networking among workers and company owners could enable integration within knowledge networks to foster extra-regional linkages in the form of localized knowledge networks (Boschma and Iammarino 2009).

Compliance with Ethical standards

Conflict of Interest The authors declare that they have no conflict of interest.

Statement of Human Rights This article does not contain any studies with human participants performed by any of the authors.

Appendix

Table 4

NAICS 4-digit	Industry / Commodity	Total
3149	Other textile product mills	12,458
3169	Manufacture of other products of leather, fur and substitute materials	1,848
3255	Paint, coating and adhesive manufacturing	478
3256	Soap, cleaning compound and Toilet preparation manufacturing	1,044
3261	Plastic products manufacturing	4,115
3262	Rubber products manufacturing	877
3314	Industries of nonferrous metals, except aluminum	131
3315	Cast molding metal parts	428
3321	Forged metal products and blanks manufacturing	476
3323	Metal structures and products blacksmith manufacturing	36,546
3324	Boilers, tanks and metal containers manufacturing	356
3327	Metalworking and manufacturing screws	8,148
3328	Coatings and metal finishing	652
3329	Other fabricated metal products manufacturing	1,126
3332	Machinery and equipment for manufacturing industries manufacturing, except metalworking	762
3333	Machinery and equipment for trade and services manufacturing	148
3335	Machinery and equipment for the metalworking industry manufacturing	355
3336	Internal combustion engines, turbines, transmissions manufacturing	50
3339	Other machinery and equipment for general industry manufacturing	718
3341	Computers and peripheral equipment manufacturing	111
3342	Communication equipment manufacturing	151
3343	Audio and video manufacturing	137
3344	Electronics Manufacturing	571
3345	Measuring instruments, control, navigation, and electronic medical equipment manufacturing	212
3352	Electrical household appliances manufacturing	240
3353	Generation and distribution of electricity manufacturing	355
3359	Other electrical equipment and fittings manufacturing	388
3363	Motor vehicle parts manufacturing	1,221
3364	Aerospace equipment manufacturing	103
3379	Mattresses, blinds and curtain rods manufacturing	363
3391	Non-electronic equipment and disposable supplies for medical, dental and laboratory use, and ophthalmic articles manufacturing	2,179
3399	Others manufactures	11,691
4342	Wholesale of raw materials for industry	39,582
4352	Wholesale of machinery and equipment for industry	2,989
4354	Wholesale furniture and computer equipment and office equipment, and other machinery and equipment for general use	7,524

Table 4 (continued)

NAICS 4-digit	Industry / Commodity	Total
4811	Scheduled air transport	178
4812	Non-scheduled air transport	107
4881	Services related to air transport	168
5413	Architectural, engineering and related activities	5,968
5414	Professional Design	3,368
5415	Services computer systems design and related services	2,829
5416	Management consulting services, scientific and technical	5,798
5511	Corporate	468
5611	Business Management Services	2,683
5615	Travel agencies and reservation services	5,847
8112	Repair and maintenance of electronic equipment and precision equipment	19,032
8113	Repair and maintenance of machinery and agricultural, industrial, commercial equipment and services	9,263
	Number of economic units	194,242

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