The evolution of manufacturing in Guanajuato: economic complexity and municipal industrial strategies

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Abstract

This text presents the evolution of the economic structure of manufacturing for the municipalities of the Mexican state of Guanajuato, using different methods from evolutionary economic geography literature *i)* to describe the evolution of specialization in manufacturing industries during the period 2003-2018; *ii)* to analyze the diversification strategies of the six most important manufacturing municipalities based on the level of economic complexity of the new branches in which they specialized; *iii)* to identify opportunities for the future diversification of manufacturing in the six municipalities, considering their most recent economic structure. The analysis may be relevant for the design of public policies to contribute to Guanajuato's economic and industrial development.

Keywords: proximity; distance capacity; economic complexity.

1. INTRODUCTION

During the last 25 years, certain regions of Mexico have significantly transformed their productive structure. Literature[1] attributes the observed changes to the economic reforms that the country initiated in the 1980s, specifically, to the easing of restrictions in order to stimulate the flow of Foreign Direct Investment (FDI) and to trade agreements with other countries in order to encourage the trade of goods and services (mainly the North American Free Trade Agreement [NAFTA]).

During this period, the state of Guanajuato and its neighbors (Aguascalientes, Querétaro and San Luis Potosí) recorded outstanding economic growth (higher than the national average), driven mainly by the growth of the transportation equipment manufacturing subsector and the productive industries to which this subsector is linked.

Recently, in the context of international economic slowdown mainly caused by the Covid-19 pandemic, national and local governments in different countries were faced with the urgent need to develop industrial strategies to reactivate and boost their economies. These included smart specialization strategies, which aim to encourage productive diversification and technification and are based on the principle of prioritization, vertical logic, and on robust data analysis methods to identify optimal areas for intervention through innovation policies (Foray, 2014). Vertical policies follow a process of identification and selection of desirable areas of intervention, which involves choices of technologies, fields and subsystems that could be favored in the regional policy framework. In turn, robust data analysis methods should serve to identify the economic activities that, on a regional level, represent the best opportunities so that when implemented, they also help to develop the greatest number of other economic activities. All in order to build regional competitive advantages based on existing productive capacities (Foray and Goenaga, 2013).

This paper has two main objectives: 1) to describe and explain the productive evolution of the municipalities of Guanajuato, which have specialized in new economic branches of the manufacturing industry during the period 2003-2018, 2) to estimate different metrics of the economic complexity methodology to analyze the industrial diversification strategies that the municipalities have used during this period, as well as to identify opportunities for future specialization in the most industrialized municipalities of the state.

The rest of the chapter is organized as follows: Section 2 describes the transformation of the economic manufacturing structure of the municipalities of Guanajuato. The economic change is illustrated by the transformation of the main municipalities that have evolved to specialize in economic branches linked to the production of transportation equipment. Section 3 presents the analysis of the industrial diversification strategies of the six most important municipalities in the state (Celaya, Irapuato, Leon, Moroleón, San Francisco del Rincon and Silao). This analysis is based on the classification of the new industries in which these municipalities have specialized during the study period (as well as those in which they no longer specialized) based on different metrics of economic complexity. Section 4 analyzes these municipalities' most recent productive structures to identify opportunities for future specialization, which will allow for an economy based on industrial technification with sustained growth. Section 5 presents the final comments.

2. DESCRIPTION OF THE EVOLUTION OF THE ECONOMIC STRUCTURE OF MANUFACTURING IN THE MUNICIPALITIES OF GUANAJUATO, 2003-2018

The economic structure of the state of Guanajuato in general and several of its municipalities in particular has evolved over the last two decades. The most economically important municipalities have specialized in more manufacturing activities, which has resulted in the state becoming one of the most important manufacturing producers in the country.

To illustrate the evolution of the manufacturing sector in the state, which is the most dynamic in the country, we used the following data in order to measure the productivity of the municipalities: Added Value (AV) divided by the Total Employed Population of each municipality by branch of economic activity.[2] The data is obtained from INEGI's Economic Censuses (EC) from 2004, 2009, 2014 and 2019. A matrix for each census lists the country's municipalities in the rows and the economic branches of manufacturing included in the North American Industrial Classification System (SCIAN) in the columns. Therefore, for each year, the matrix entries show the AV per worker for each municipality in each branch. These data matrices will be called *Mt*, where *t* indicates each year of the sample.

Evidence of the evolution of the productive capacities of the municipalities can be obtained thanks to a simple procedure widely used in the literature referring to regional economics. Using the described data matrices, we can obtain the number of economic branches each municipality specializes in.[3] Table 1 shows the number of manufacturing branches in which each municipality specializes in the different years of the sample. It is clear that there is a general trend over time, and the municipalities increase their productive expertise, i.e., the number of branches of manufacturing in which they specialize increases. According to the 2019 EC, the state’s municipalities specialized, on average, in three new manufacturing branches compared to what was recorded in the 2004 EC.

Table 1. Branches of manufacturing in which the municipalities specialize*

Municipality	*2004*	*2009*	*2014*	*2019*
Abasolo	5	8	6	9
Acámbaro	12	8	7	9
Apaseo el Alto	7	9	11	12
Apaseo el Grande	9	7	9	13
Atarjea	0	0	0	0
Celaya	33	29	32	39
Manuel Doblado	8	10	6	13
Comonfort	8	11	8	13
Coroneo	4	6	5	6
Cortazar	11	7	8	11
Cuerámaro	5	4	4	9
Doctor Mora	5	5	4	7
Dolores Hidalgo	6	9	10	12
Guanajuato	8	4	5	11
Huanímaro	2	4	1	7
Irapuato	35	29	33	42
Jaral del Progreso	7	9	5	11
Jerécuaro	4	5	3	8
León	43	40	45	51
Moroleón	13	11	12	23
Ocampo	3	4	3	6
Pénjamo	9	10	7	9
Pueblo Nuevo	5	6	3	4
Purísima del Rincón	12	19	18	18
Romita	9	8	5	6
Salamanca	12	11	17	14
Salvatierra	6	11	6	7
Municipality	*2004*	*2009*	*2014*	*2019*
S. Diego de la Unión	3	6	2	8
San Felipe	4	4	7	10
S. Francisco Rincón	19	23	23	27
San José Iturbide	8	9	14	13
San Luis de la Paz	5	7	6	1
San Miguel de Allende	13	16	12	12
Santa Catarina	2	3	4	3
S.C. Juventino Rosas	9	10	7	16
Santiago Maravatío	2	2	2	4
Silao	7	9	13	23
Tarandacuao	6	6	3	4
Tarimoro	9	5	2	9
Tierra Blanca	4	3	3	6
[illegible]	[illegible]	7	[illegible]	[illegible]

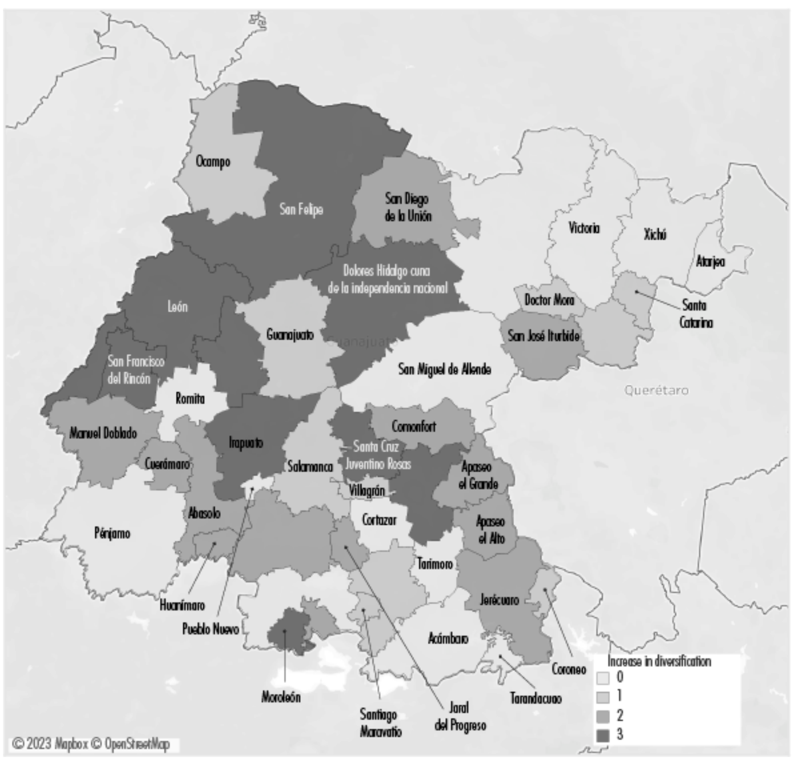
Uriangato	12	7	13	16
Valle de Santiago	8	4	6	12
Victoria	4	3	5	2
Villagrán	7	5	8	8
Xichú	2	1	2	2
Yuriria	10	7	6	10

Note: *SCIAN has 86 different economic branches in the manufacturing sector.

Source: Compiled by the authors based on the 2004 and 2019 ECs.

Figure 1 spatially illustrates the progress of specialization in the municipalities during the period. This figure has four categories: *i)* number 0 (lighter color) shows municipalities that had a setback or zero progress in relation to the number of new branches; *ii)* number 1 denotes municipalities that added one or two new branches (minimum progress); *iii)* number 2 indicates municipalities that specialized in three, four or five new branches (moderate progress); and, finally, *iv)* number 3 indicates municipalities that added six or more branches of manufacturing (maximum progress). It is clear that, in general, the municipalities closest to the so-called industrial corridor specialize in the largest number of manufacturing activities.[4] Leon is the most important municipality with specialization in almost 60% of the branches of manufacturing, followed by Irapuato and Celaya with 49 and 45%, respectively; San Francisco del Rincon with 31%, and Moroleón and Silao with 27%, which completes the municipalities that specialize in more than 25% of branches. In general, municipalities in the north and south of the state tend to specialize in fewer manufacturing branches.

Figure 1. Increase in the diversification of municipalities



Source: compiled by the authors based on the 2004 and 2019 ECs.

Economic branches of manufacturing in which the municipalities of Guanajuato specialize

The growth of the transportation equipment manufacturing subsector was an important driver of growth in the state of Guanajuato during the period analyzed. This is reflected in the branches of manufacturing in which some of the municipalities in the state specialize. Table 2 shows the main economic branches that provide inputs and intermediate products to the branches of the transportation equipment subsector (3361 Manufacture of automobiles and trucks; 3362 Manufacture of vehicle bodyworks and trailers; 3363 Manufacture of parts for motor vehicles; 3364 Manufacture of aerospace equipment; 3365 Manufacture of railway equipment; 3366 Manufacture of boats; and 3369 Manufacture of other transportation equipment).

Table 2. Percentage of purchases by branches of the transportation equipment subsector

Primary intermediate input supply industries	*Branches of the transportation equipment subsector* [a]						
	3361	*3362*	*3363*	*3364*	*3365*	*3366*	*3369*
3261 Plastic products	0.04	0.01	0.03	0.00	0.00	0.01	0.04
3262 Rubber products	0.04	0.05	0.01	0.00	0.00	0.01	0.06
3272 Glass and glass products	0.02	0.00	0.00	0.00	0.00	0.00	0.00
3311 Basic iron and steel industry	0.02	0.16	0.04	0.01	0.27	0.12	0.01
3312 Iron and steel products	0.01	0.10	0.05	0.00	0.01	0.12	0.03
3313 Aluminum industry	0.01	0.05	0.02	0.05	0.00	0.00	0.00
3329 Other metal products	0.01	0.03	0.04	0.01	0.03	0.02	0.02
3336 Manufacture of combustion engines	0.04	0.00	0.02	0.04	0.00	0.06	0.06
3359 Manufacture of electrical equipment and accessories	0.01	0.00	0.04	0.02	0.00	0.00	0.01
3361 Manufacture of automobiles and trucks	0.02	0.01	0.00	0.00	0.00	0.00	0.00
3362 Manufacture of vehicle bodywork and trailers	0.03	0.05	0.00	0.00	0.00	0.00	0.00
3363 Manufacture of parts for motor vehicles	0.49	0.11	0.15	0.04	0.03	0.05	0.21
4311 Wholesale trade of groceries and food products	0.16	0.10	0.08	0.06	0.15	0.10	0.05
4611 Retail trade of groceries and food products	0.02	0.01	0.01	0.01	0.02	0.01	0.01
4841 Freight transportation	0.03	0.01	0.01	0.02	0.04	0.02	0.01
5613 Employment services	0.01	0.03	0.04	0.05	0.02	0.10	0.03
Total	0.92	0.74	0.53	0.31	0.57	0.62	0.54

Note: [a] The values in the table refer to the percentage of purchases of intermediate inputs with respect to total purchases made by each branch of the transportation subsector (columns) from its suppliers (rows).

Source: Mexico input-output matrix 2013, INEGI.

Identifying the value chains of the region's key industries is a fundamental aspect of the smart specialization strategy and the generation of greater added value. Examples on an international level show that the most successful linkages go backward in the chain, not forwards. Developing linkages that are in demand locally will make it possible to increase productive know-how in the region. However, this will only be achieved if the linkages are based on local industry and educational and research centers can provide specialized technology and human capital.

As shown in Figure 2, during the period 2003-2018, Silao was the municipality that provided evidence of the substantial change in the economic structure of the state. This was not only because of the number of new economic branches in which it specialized (16) but also because many of them were directly related to the production of transportation equipment. The most closely related were listed first: 3261, 3312, 3313, 3329, 3359 and 3361. It also specialized in other branches associated with the manufacture of transportation equipment: 3169 Manufacture of other leather, fur and leather substitute products; 3252 Manufacture of synthetic resins and rubber, and chemical fibers; 3255 Manufacture of paints, coatings and adhesives; 3315 Casting of metal parts; 3327 Machining of parts and manufacture of screws; 3328 Metal coatings and finishes; and 3339 Manufacture of other machinery and equipment for general industry.

Figure 2. Change in municipal specialization 2003-2018 in branches of manufacturing supplying the transportation equipment subsector*

Rama	Celaya, Gto.	Irapuato, Gto.	León, Gto.	Moroleón, Gto.	San Francisco del Rincón, Gto.	Silao de la Victoria, Gto.
3261 Manufacture of plastic products	■	■	□	□	□	■
3262 Manufacture of rubber products	□	■	■	□	■	□
3272 Manufacture of glass and glass products	□	■	□	□	■	□
3311 Basic iron and steel industry	□	□	□	□	□	□
3312 Manufacture of iron and steel products	■	■	□	□	□	■
3313 Basic aluminum industry	□	■	■	□	□	■
3329 Manufacture of other metal products	■	■	■	□	■	■
3336 Manufacture of internal combustion engines and turbines	□	□	□	□	□	□
3359 Manufacture of other electrical equipment and accessories	■	□	■	□	□	■
3361 Manufacturing of automobiles and trucks	□	□	□	□	□	■
3362 Manufacture of vehicle body work and trailers	■	■	■	□	□	□
3363 Manufacture of parts for motor vehicles	■	■	□	□	□	■

*Note: *the specialization (marked in dark gray) refers to the supplier branches of the Transportation Equipment subsector in which each municipality had a comparative advantage equal to or greater than 1.*

Source: Compiled by the authors based on the 2004 and 2019 ECs.

The next municipality with significant transformation is Irapuato. It specialized in some of the branches mentioned in Table 2, such as 3261, 3312, 3313 and 3363, in addition to 3252 Manufacture of synthetic resins and rubbers, and chemical fibers; 3326 Manufacture of wire, wire products and springs; 3328 Metallic coatings and finishes; and 3339 Manufacture of other machinery and equipment for general industry.

3. MUNICIPAL INDUSTRIAL DIVERSIFICATION STRATEGIES

To generate sustained economic growth, countries and regions of the world transform their productive structures to produce more diverse goods with greater added value; in other words, they develop new comparative advantages.

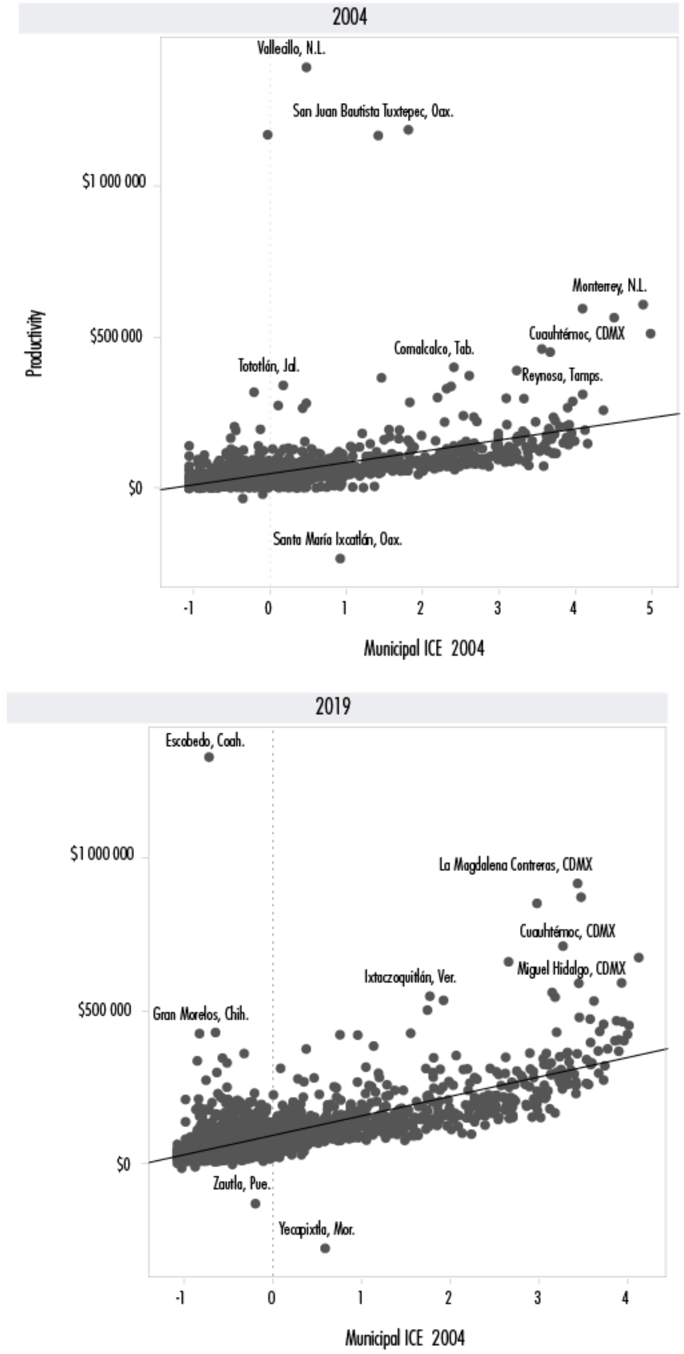
Although the diversification in production observed in the industrial corridor of Guanajuato complies with this principle of development, the generation of greater added value based on innovation and the generation of new knowledge implies that new industries have a more technological base and more specialized human capital. On the other hand, as suggested by evolutionary economic geography studies, the opportunities for diversification in regional production towards more high-tech industries are usually determined by their accumulated historical production capacities. In other words, the development of new industries is based on the principle of path dependence (Boschman and Frenken, 2018; Hidalgo et al., 2007; Hausmann et al., 2014).

In this context, two relevant questions regarding the state's economic development are: 1) is the diversification in production of the municipalities based on said path dependency? and 2) do the new industries encourage the accumulation of more sophisticated, higher added value productive knowledge in the municipalities?

The economic complexity methodology is one of the most widely used techniques to classify economies and economic activities based on the productive knowledge they possess or require. Based on its use, it is possible to design intelligent specialization strategies that take local comparative advantages as a starting point (see Annex 3 for a detailed methodology for calculating economic complexity). As shown in international literature and literature applied to Mexico, the Index of Economic Complexity (ICE) of regions and activities or products is closely related to aspects of development, such as economic growth, income, inequality, and even carbon emissions (Hidalgo and Hausmann, 2009; Hidalgo, 2021; Chávez et al. 2017, among others).

The analysis found that the ICE of municipalities and industrial branches is positively linked to the measure of productivity (average added value per employee). In the case of municipal economic complexity, as shown in Figure 3, a positive relationship exists between municipal ICE and productivity in a sample of more than 2,400 municipalities in Mexico. This indicates that municipalities with greater economic complexity in the country, with more productive knowledge, also on average have higher productivity. In turn, the ICI in Mexico also has a positive relationship with productivity in a sample of 86 branches (see Figure 4). This indicates that the branches of economic activity that require the most productive knowledge are those with the highest productivity levels.

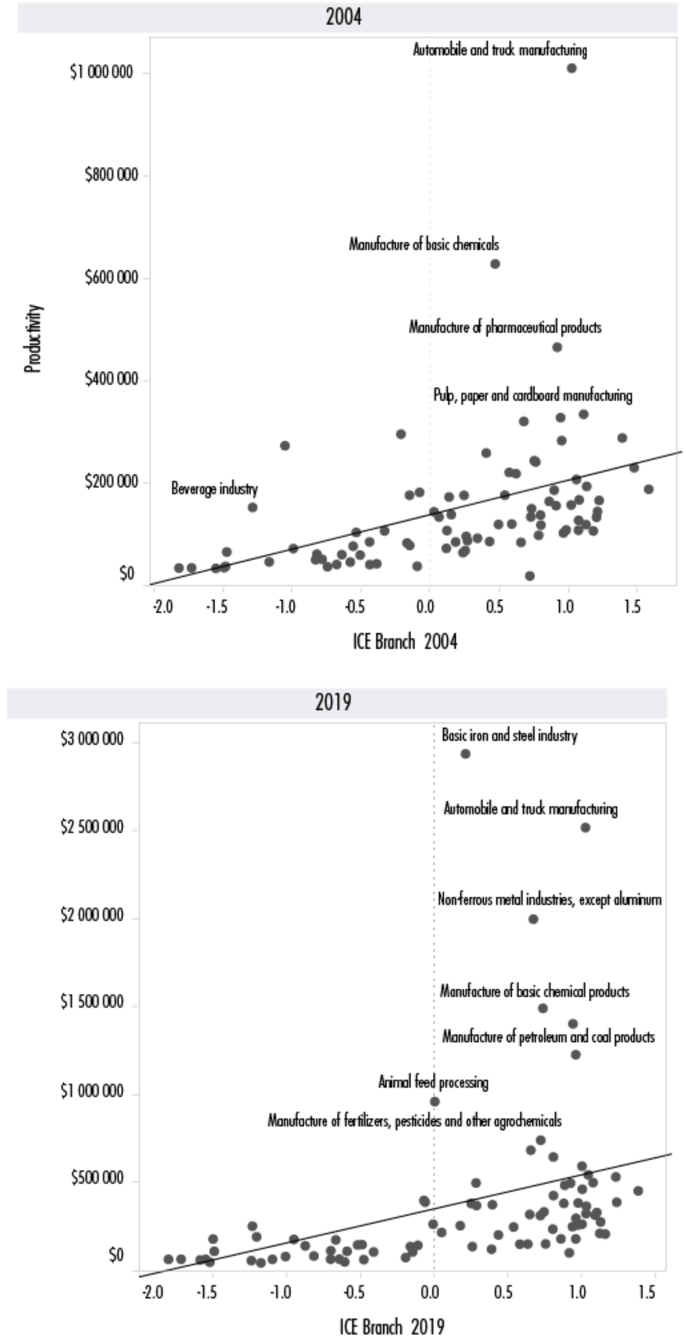
Figure 3. Municipal economic complexity and average productivity*



*Note: *The figures include 2,447 municipalities in 2003 and 2,463 municipalities in 2019. For ease of visualization, in 2019 the municipality of Azcapotzalco, Mexico City, the most complex municipality in this period with an ICE of 5.45 and productivity of MXN $8,216,402.80, is excluded.*

Source: Compiled by the authors based on the 2004 and 2019 ECs.

Figure 4. Manufacturing economic complexity and average productivity*



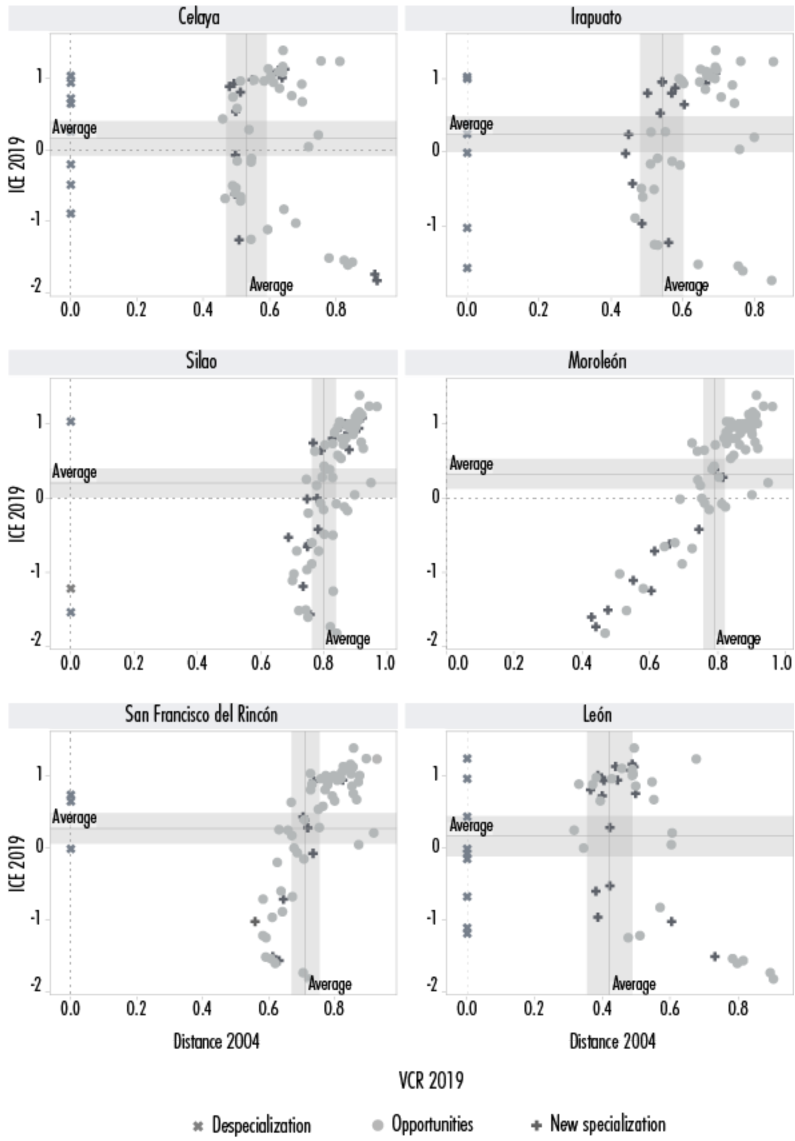
*Note: *the figures for 2004 and 2019 include 85 and 86 manufacturing branches, respectively.*

Source: Compiled by the authors based on the 2004 and 2019 ECs.

In this context, to answer the first question about the path of productive municipal diversification, estimates were made of the capacity distance of each municipality in the country from the economic branches in which it does not specialize. This measure begins by considering the comparative advantages of the municipality to calculate based on the proximity between industries. This metric indicates a municipality's capacity distance with regard to developing a new industry considering its current productive structure. Specifically, if a municipality is already specialized in the branches related to a new industry, the distance measure will be short, close to 0; otherwise, the distance will be long, close to 1 (for more details on the methodology, see Annex 4).

Figure 5 presents the results of this analysis. The horizontal axis shows the measurement of the capacity distance for each municipality based on the productive structure presented in the 2004 EC. The vertical axis gives the complexity index of the branches of manufacturing calculated in the 2019 EC. The shapes of the marks indicate the changes in the municipality's specialization: *i)* "+" marks show those new branches in which the municipality specialized from 2004 to 2019; *ii)* "x" marks show those branches in which the municipality was specialized in 2004, but no longer specializes in 2019; *iii)* "•" dots show the remaining branches of manufacturing that continue to represent opportunities for diversification in production.

Figure 5. Municipal strategies for diversification of production



Source: Compiled by authors based on the 2004 and 2019 ECs

In general, we can see how the municipalities of Celaya, Irapuato and Silao followed aggressive strategies for diversification in production (whether or not explicit) by specializing in manufacturing branches with a high level of complexity and a high-capacity distance (upper right quadrant). Meanwhile, the municipalities of León and San Francisco del Rincón used less risky strategies by diversifying towards industries close to their average capacity distance (a strategy more in line with the path dependency principle) and with different levels of complexity with respect to the average 2019 ICE. Finally, Moroleón followed a more conservative strategy, diversifying into industries with a reduced capacity distance from its productive structure with a below-average 2019 ICE (lower left quadrant).

The strategies followed by the municipalities help to understand the results obtained in comparative terms on a national level. In this sense, to answer the second question, it is important to analyze whether the diversification in production registered in the 2004 and 2019 ECs had any impact on the level of sophistication of the productive structures of the leading industrial municipalities of Guanajuato with respect to the rest of the municipalities in Mexico. For this purpose, the ICE was estimated for more than 2,400 municipalities using the productivity variable described above. This index makes it possible to classify productive municipal structures based on their diversity (number of economic branches in which they specialize) and the ubiquity of the branches in which they specialize (number of municipalities that also specialize in those branches). This allows us to obtain an indicator in order to evaluate the amount of productive knowledge possessed by the municipality.

As shown in Table 3, some municipalities in the state managed to climb several places in the ranking of municipal economic complexity, while others had setbacks. Specifically, Celaya rose from 39th place out of a total of 2,447 municipalities in 2004 to 22nd place in 2019; Irapuato went from 64th place to 50th place; Silao from 143rd place to 104th place; and San Francisco del Rincón from 147th place to 139th place in the same period. On the other hand, the municipality of León fell in the ranking from 29th to 35th place, and the municipality of Moroleón, despite its progress in relation to diversification during the period, dropped from 215th to 281st place.

Table 3. Municipal ICE ranking 2004 and 2019

No.	Municipality	ICE 2004	No.	Municipality	ICE 2009
1	Cuauhtémoc, Mexico City	4.98	1	Azcapotzalco, Mexico City	5.45
2	Monterrey, Nuevo León	4.88	2	Cuauhtémoc, Mexico City	4.11
3	Venustiano Carranza, Mexico City	4.50	3	San Luis Potosí, San Luis Potosí	4.00
	↓			↓	
29	León, Guanajuato	3.64	22	Celaya, Guanajuato	3.57
39	Celaya, Guanajuato	3.55	35	León, Guanajuato	3.41
64	Irapuato, Guanajuato	3.20	50	Irapuato, Guanajuato	3.23
143	Silao de la Victoria, Guanajuato	2.28	104	Silao de la Victoria, Guanajuato	2.66
147	San Francisco del Rincón, Guanajuato	2.22	139	San Francisco del Rincón, Guanajuato	2.37
215	Moroleón, Guanajuato	1.47	281	Moroleón, Guanajuato	1.22
	↓			↓	
2445	Magdalena, Veracruz	-1.07	2462	Santo Domingo Roayaga, Oaxaca	-1.08
2446	Mixtla de Altamirano, Veracruz	-1.07	2463	La Trinidad Vista Hermosa, Oaxaca	-1.08
2447	Sochiapa, Veracruz	-1.07	2464	Oquitoa, Sonora	-1.08

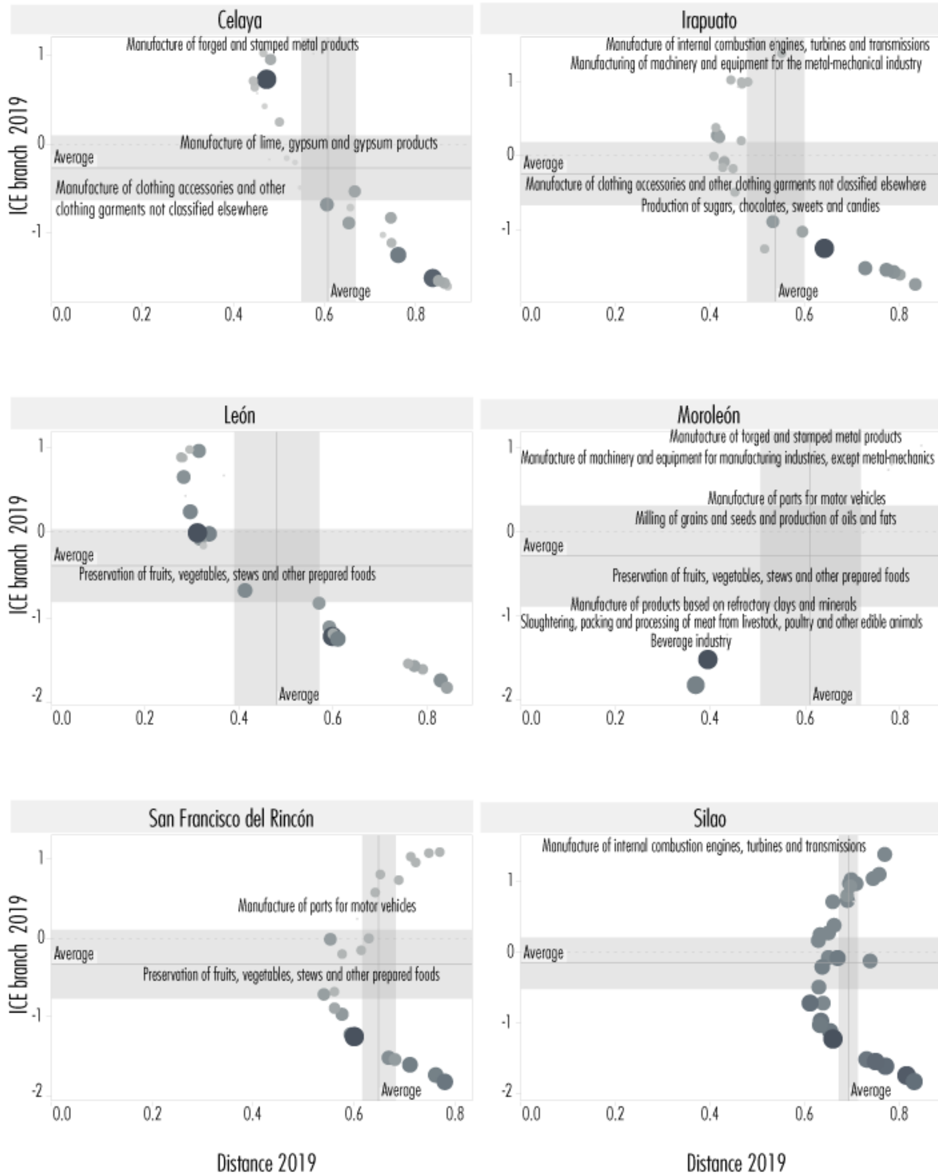
Source: compiled by the authors based on the 2004 and 2019 ECs.

4. OPPORTUNITIES FOR FUTURE SPECIALIZATION AND DIVERSIFICATION

Based on the previous analysis, this section aims to identify opportunities for future diversification into more sophisticated manufacturing branches in each municipality. To this end, measures of economic complexity were estimated for the most current period for which data is available.

Specifically, the horizontal axis of figure 6 presents the measurement of the capacity distance of each municipality from each manufacturing branch; the vertical axis refers to the complexity index of each manufacturing branch. Finally, for the purposes of the analysis, the color and size of the dots in the graphs refer to the level of productivity of the manufacturing branch in the municipality (larger, darker dots refer to branches with higher productivity).

Figure 6. Opportunities for future specialization and diversification



Source: Compiled by authors based on the 2004 and 2019 ECs.

Based on this approach, opportunities for future specialization and diversification are inferred from these metrics in this order: 1) prioritizing branches of higher complexity; 2) prioritizing branches in which the municipality has higher productivity (productivity ≠ 0); 3) prioritizing branches with a lower capacity distance. In this way, three types of strategy are inferred in which the six most industrialized municipalities of Guanajuato could be located:

Low-risk, high-return strategy

The municipalities of Celaya and León, the most complex in the state, present opportunities to consolidate manufacturing branches of high complexity and affinity with their current productive structure (upper left quadrant). In this respect, the suggested strategy consists of promoting their specialization in these branches and making them more competitive on a national level. This requires exploring opportunities for productive diversification along the value chains, which will not necessarily be found within the manufacturing industries. Additionally, as leading industrial municipalities, they can seek to consolidate their productive structures and key industries by taking advantage of the specialization of neighboring municipalities. As the literature suggests, the analysis of opportunities for specialization and productive diversification towards more sophisticated industries in the tertiary sector will be important at this level of their productive structure.

Low-risk, medium-return strategy

The most important opportunities for specialization for the municipalities of Irapuato, Silao and San Francisco del Rincón are located in the low-risk quadrants (upper and lower left quadrants), where some medium complexity branches that exhibit similarities with their current productive structure are located. It is also important to note that the manufacturing branches with the highest productivity in these municipalities are located in the lower right quadrant but are of very low complexity. Therefore, a second proposal would be to increase the technology of these industries backward along their value chain, identifying those supplier industries that are more similar to their productive structure.

Low-risk reward or high-risk reward strategies

The most immediate opportunities in the municipality of Moroleón, the least complex of the six municipalities under analysis, are in the specialization of manufacturing branches on which its economy bases its productivity. These branches are related to the current productive structure, with low complexity (lower left quadrant), so a two-fold strategy is suggested. Firstly, achieve specialization in these industries through increased technology; secondly, and in parallel, leverage its medium-term vision in a higher-risk strategy based on developing more sophisticated industries that are not currently present in the municipality. The selection of these industries should consider the principle of affinity with its current productive structure and the industries' complexity and, more strategically, should aim to match the productive structures of the leading industrial municipalities through the needs of their value chains.

In general, it is suggested that the strategy to generate greater added value and innovation in key manufacturing industries in the region will depend, to a large extent, on the development of local suppliers along the entire value chain of these industries. As mentioned earlier, international success stories show that backward linkages in the value chain generate better results. Therefore, as part of the smart specialization strategy, the links in the chain most dependent on global value chains need to be identified in order to reduce this dependence in the medium term on local suppliers and generate greater benefits from agglomeration economies. Likewise, identifying artificial intelligence technologies, remote management, manufacturing and/or harvesting robots, etc., in each of the links will be crucial in order to prioritize projects and investments in research and development, generation of technology-based startups, training of specialized human capital (current and future), etc.

Finally, table 4 presents the prioritization of the five manufacturing branches in which each municipality should specialize and around which innovation should be generated based on the principles of complexity, productivity and capacity distance.

Table 4. Prioritization of manufacturing branches by municipality

SCIAN	Branch	ICE	Productivity ($)	Distance
Celaya				
3321	Manufacture of forged and punched metal products	1.03	76 553	0.46
3241	Manufacture of petroleum and coal products	0.96	147 320	0.48
3251	Manufacture of basic chemicals	0.74	441 590	0.47
3315	Casting of metal parts	0.65	84 828	0.45
3272	Manufacture of glass and glass products	0.43	38 263	0.47
Irapuato				
3256	Manufacture of soaps, cleansers and toilet preparations	0.28	109 786	0.42
3391	Manufacture of non-electronic equipment and disposable medical, dental and laboratory supplies and ophthalmic articles	0.26	73 488	0.42
3259	Manufacture of other chemical products	-0.07	53 750	0.43
3113	Manufacture of sugars, chocolates, candies and similar products	-0.88	112 841	0.53
3271	Manufacture of products based on refractory minerals and clays	-1.01	74 886	0.60
León				
3353	Manufacture of electric power generation and distribution equipment	0.98	59 900	0.29
3241	Manufacture of petroleum and coal products	0.96	166 091	0.31
León				
3324	Manufacture of boilers, tanks and metal containers	0.89	82 867	0.28
3328	Metallic coatings and finishes	0.88	65 344	0.28
3312	Manufacture of iron and steel products	0.65	162 729	0.28
Moroleón				
3112	Grain and seed milling and extraction of oils and fats	-0.06	40 800	0.69
3121	Beverage industry	-1.51	68 710	0.39
3118	Production of bakery products and tortillas	-1.81	58 311	0.37
3271	Manufacture of products based on refractory minerals and clays	-1.01	-	0.44
3116	Slaughtering, packing and processing of meat from livestock, poultry and other edible animals	-1.21	-	0.44
San Francisco del Rincón				
2382	Building installations and equipment	0.28	64 500	0.57
3111	Animal feed processing	0.00	4 856	0.63
3261	Manufacture of plastic products	-0.01	44 898	0.55
3279	Manufacture of other products based on non-metallic minerals	-0.71	41 889	0.54
3113	Manufacture of sugars, chocolates, candies and similar products	-0.88	25 400	0.56
Silao				
2383	Finishing works in buildings	0.61	33 000	0.63
3259	Manufacture of other chemical products	-0.07	46 200	0.67
3141	Manufacture of carpets, linen and similar items	-0.20	29 286	0.64
3279	Manufacture of other products based on non-metallic minerals	-0.71	88 143	0.61
3119	Other food industries	-0.96	66 875	0.63

Source: compiled by the authors

5. CONCLUDING REMARKS

This article describes the evolution of the manufacturing industry in the municipalities of the state of Guanajuato for the period considered in the 2004-2019 ECs. It is the sector that gave the most economic impulse to the state in this period.

Estimates reveal that the state's municipalities advanced in the number of manufacturing economic branches they specialize in. In 2018 they specialized, on average, in three new branches compared to 2003. The municipalities of the industrial corridor are not only the most specialized in the number of industrial branches in this sector but also presented the greatest progress in the period.

Celaya, Irapuato, Silao and San Francisco del Rincón stand out because they specialize in the most economically complex branches, i.e., economic activities requiring more productive knowledge. This allowed these municipalities to advance in the ranking of municipalities by level of complexity and by 2018, they possessed economic structures capable of carrying out economic activities that produced goods with higher added value. The municipalities of León and Moroleón, despite having specialized in new branches, suffered a setback in the same classification of municipalities on a national level. This implies that some municipalities in the country made more significant progress.

Finally, the methods used made it possible to identify manufacturing branches in which the municipalities can specialize in the future. Given their economic structure in 2018, there are economic activities that require capacities similar to those already present in the municipalities due to the economic activities they already carry out. Given that they have a small capacity distance, the diversity of these branches in which municipalities can specialize shows that the municipalities remain diverse.

ANNEX 1

The SCIAN divides the manufacturing sector into the following 21 subsectors and 86 branches:

Table A1.1 Subsectors and branches of the manufacturing sector, SCIAN 2018

Subsector	*Branches*
311 Food industry	3111 Animal feed
	3112 Grains, seeds, oils and fats
	3113 Sugars, chocolates, candies, sweets and similar
	3114 Preservation of fruits, vegetables and other foods
	3115 Dairy products
	3116 Packaging and processing of meat, poultry and other products
	3117 Preparation and packaging of fish and seafood
	3118 Bakery and tortillas
	3119 Other food industries
312 Beverage and tobacco industry	3121 Beverage industry
	3122 Tobacco industry
313 Textile supplies and finishes	3131 Spinning of textile fibers and yarn manufacturing
	3132 Fabrics
	3133 Coated fabrics
314 Textile products (except clothing)	3141 Carpets, blanks and similar
	3149 Other textile products, except clothing
315 Clothing	3151 Knitted clothing
	3152 Manufacture of clothing
	3159 Manufacture of accessories and other clothing
316 Leather and fur, leather and fur products and substitutes	3161 Tanning and finishing of leather and fur
	3162 Manufacture of footwear
	3169 Other leather, fur and leather substitute products
321 Wood industry	3211 Sawmilling and wood preservation
	3212 Wood laminates and agglutinates
	3219 Other wood products
322 Paper industry	3221 Pulp, paper and cardboard
	3222 Paper and cardboard products
323 Printing and related industries	3231 Printing and related industries
324 Petroleum and coal products	3241 Petroleum and coal products
325 Chemical industry	3251 Basic chemical products
	3252 Synthetic resins and rubbers and chemical fibers
	3253 Fertilizers, pesticides and other agrochemicals
	3254 Pharmaceutical products
	3255 Paints, coatings and adhesives
	3256 Soaps, cleansers and toiletries
	3259 Other chemical products
326 Plastics and rubber industry	3261 Plastic products
	3262 Other rubber products

Subsector	*Branches*
327 Non-metallic mineral-based products	3271 Products based on clays and refractory materials
	3272 Glass and glass products
	3273 Cements and concrete products
	3274 Lime, plaster and plaster products
	3279 Other non-metallic mineral-based products
331 Basic metal industries	3311 Basic iron and steel industry
	3312 Manufacture of iron and steel products
	3313 Basic aluminum industry
	3314 Non-ferrous metal industry, except aluminum
	3315 Casting molding of metal parts

Subsector	Branches
332 Manufacture of metal products	3321 Forged and stamped metal products
	3322 Metal hand tools and kitchen utensils
	3323 Metal structures and fabricated metal products
	3324 Metal boilers, tanks and containers
	3325 Hardware and locks
	3326 Wire, wire products and springs
	3327 Machining of parts and screw manufacturing
	3328 Metal coatings and finishes
	3329 Manufacture of other metal products
333 Manufacture of machinery and equipment	3331 Agricultural machinery and equipment
333 Manufacture of machinery and equipment	3332 For manufacturing, except metal-mechanics
	3333 For trade and services
	3334 Air conditioning, heating and industrial
	3335 For the metalworking industry
	3336 Internal combustion engines, turbines and transmitters
	3339 Other machinery
334 Computer, communication, measuring and other electronic equipment, components and accessories	3341 Computers and peripheral equipment
	3342 Communication equipment
	3343 Audio and video equipment
	3344 Electronic components
	3345 Measuring, control and navigation instruments
	3346 Magnetic and optical media
335 Electrical accessories, apparatus and equipment for the generation of electricity	3351 Manufacture of lighting fixtures
	3352 Manufacture of electrical appliances for domestic use
	3353 Equipment for the generation and distribution of electricity
	3359 Other electrical equipment and accessories
336 Manufacture of transportation equipment	3361 Manufacture of cars and trucks
	3362 Manufacture of vehicle bodies and trailers
	3363 Manufacture of parts for motor vehicles
	3364 Manufacture of aerospace equipment
	3365 Manufacture of railway equipment
	3366 Manufacture of boats
	3369 Manufacture of other transport equipment
337 Furniture, mattresses and blinds	3373 Furniture, except office furniture and shelves
	3372 Office furniture and shelving
	3379 Mattresses, blinds and drapes
339 Other manufacturing industries	3391 Non-electronic medical, dental, laboratory and ophthalmic disposable equipment and supplies
	3399 Other manufacturing industries

Source: compiled by authors based on the 2018 SCIAN.

ANNEX 2

Calculation of the specialization matrix

To transform the productivity matrix (VA per worker), *Mt*, into what will be called the specialization matrix $M^{t}_{m,a}$, a matrix of zeros and ones,[5] the definition of Location Quotient (LC) is used. For the 2019 EC:

(1)

$$CL_{m,a} = \frac{\frac{VA_{m,a}}{\sum_{a=1}^{86} VA_{m,a}}}{\frac{\sum_{m=1}^{2463} VA_{m,a}}{\sum_{a=1}^{86} VA_{m,a} \sum_{m=1}^{2463} VA_{m,a}}}$$

where $VA_{m,a}$ is the productivity of municipality *m*, in branch *a*; $\sum_{a=1}^{86} VA_{m,a}$ is the productivity of all economic branches in municipality *m*; $\sum_{m=1}^{2463} VA_{m,a}$ is the productivity of all municipalities in each economic branch *a*; finally, $\sum_{a=1}^{86} VA_{m,a} \sum_{m=1}^{2463} VA_{m,a}$ is the productivity of all branches in all municipalities.

Each matrix entry is defined as follows:

$$m_{m,a} = \begin{cases} 1 & \text{if } CL_{m,a} \geq 1 \\ 0 & \text{otherwise} \end{cases}$$

A municipality, *m*, specializes in economic activity *a* if the proportion of the productivity of economic activity *a*, with respect to the total productivity of the municipality, is equal to or greater than the comparable proportion of the state.

ANNEX 3

Methodology for the calculation of the Economic Complexity Index (ECI)

Once the $CL_{m,a}$ matrix is specified, it is used to define two dimensions, diversity and ubiquity, of the economic structure of the municipalities. These dimensions will be used to calculate the ICE of the municipalities and of the branches of economic activity, as well as measures of proximity between branches and measurements of distance between the municipalities and the industrial branches in which each municipality is not specialized. Diversity and ubiquity are defined as follows,

Diversity: $k_{m,0} = \sum_c CL_{m,a}$ (2)

Ubiquity: $k_{a,0} = \sum_e CL_{m,a}$ (3)

For calculations using the 2019 EC data, diversity is a vector of 1 column and 2,463 rows showing the number of different economic branches each municipality specializes in. Each entry is the sum of the rows of the $CL_{m,a}$ matrix whose values are between 1 and 86. Diversity is considered the basic measure of the amount of productive knowledge possessed by each municipality, manifested through its productive variety.

Ubiquity is a vector of 1 row and 86 columns showing the number of specialized municipalities in each economic branch. Each entry is the sum of the columns of the $CL_{m,a}$ matrix whose values are between 1 and 2,463. In this methodology, ubiquity to contributes important information to the diversity measure to infer the type of productive capacities possessed by each municipality.

Method of Reflections (MR)

The MR combines the two measures that describe the productive structure of each of the country's states, diversity and ubiquity, and this combination provides us with the economic complexity indexes of the municipalities and economic branches. These measures consist of iteratively calculating the average value of the previous values of diversity and ubiquity, starting with their initial values defined in equations (2) and (3).

Equations (4) and (5) describe the iterative process to obtain the subsequent diversity and ubiquity values, respectively. In the first case, the $CL_{m,a}$ matrix is multiplied by the initial ubiquity vector and divided by the initial diversity values. In the second case, the $CL_{m,a}$ matrix is multiplied by the initial diversity vector and divided by the initial ubiquity values. Formally, the iterative process is defined as follows:

$$k_{m,N} = \frac{1}{k_{m,0}} \sum_{a=1}^{n} CL_{m,a} \cdot k_{a,N-1} \quad (4)$$

$$k_{a,N} = \frac{1}{k_{a,0}} \sum_{m=1}^{n} CL_{m,a} \cdot k_{m,N-1} \quad (5)$$

for $N \geq 1$, where *N* refers to the iteration number. In each iteration, the ranking of the municipalities is observed according to $k_{m,N}$ and the iterations continue until the ranking of the states does not change in three consecutive iterations (a fixed point is reached). The final values at $k_{m,N}$ rank the states according to their level of economic complexity. Based on the final economic complexity values of the municipalities $k_{m,N}$ the complexity of the economic branches is calculated using equation (5) to obtain a final $k_{a,N}$.

ANNEX 4

Calculation of capacity distance

This measurement is calculated based on the proximity between economic branches. The proximity between two branches is a measurement that quantifies the set of similar knowledge or capacities shared by that pair of branches. Formally, it is the conditional probability that a municipality specializes in branch *a*, given that it specializes in *a'*. Using the $CL_{m,a}$ matrix, the proximity between economic branches *a* and *a'* is calculated as follows:

$$\emptyset_{a,a'} = \frac{\sum_m CL_{ma} \cdot CL_{ma'}}{(k_{a,0} k_{a'0})} \qquad (6)$$

Where $k_{a,0}$ and $k_{a',0}$ represent the ubiquity of the economic branch *a* and *a'*, respectively.

In this case, for the 2019 EC data, matrix $\emptyset_{a,a'}$ is 86x86, and each of its entries have values between 0 and 1.[6] Values closer to 1 indicate that branches *a* and *a'* share a greater number of capacities and thus have a greater proximity. Values close to 0 indicate that the two branches do not share many productive capacities or are not very close.[7] Matrix $\emptyset_{a,a'}$ will be used to calculate the measure of distance that each municipality has in relation to the most complex economic branches produced in Mexico.

Calculation of the capacity distance

To determine the potential of each municipality to develop new productive branches, a measure is required that quantifies the distance, in terms of capacities, of each one in relation to the branches in which they are not yet specialized. The measure of distance refers to the similarity between the capacities required by a pair of goods based on the probability that they are jointly produced with comparative advantage. To quantify this similarity, it is inferred that if two goods share the majority of the capacities required to be produced, municipalities specializing in the first will have a greater probability of specializing in the second. Thus, the measure of distance in terms of capacities is based on the measurement of proximity, i.e., the joint probability that a municipality that produces the first good will also produce the second.

Specifically, the measure of capacity distance is the sum of the proximities connecting new branch *a* with all economic activities in which municipality *m* is not specialized. This measure is obtained by dividing it by the sum of the proximities of all branches to branch *a*. Formally, it is defined as follows:

$$d_{m,a} = \frac{\sum_{a'} (1 - CL_{ma'}) \, \emptyset_{aa'}}{\sum_{a'} \emptyset_{aa'}} \qquad (7)$$

If a municipality specializes in economic branches very close to economic branch *a*, in which it does not specialize, then the capacity distance will be small, close to 0. On the other hand, if the municipality specializes in economic branches not close to branch *a*, then the capacity distance with branch *a* will be larger, close to 1.

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[1] See Hanson (1998), Rodriguez-Oreggia (2005), Cabral and Mollick (2012), Jordaan and Rodriguez-Oreggia (2012), Chavez et al. (2017), Gomez-Zaldivar et al. (2020), among others.

[2] The different branches are those covered by SCIAN. Appendix 1 shows the subsectors and branches into which SCIAN classifies the manufacturing sector.

[3] Appendix 2 explains how to calculate a specialization matrix.

[4] The municipalities of the industrial corridor are the backbone of the Guanajuato economy, distributed from east to west, and generate just over 85% of the state's Gross

Domestic Product (GDP). They include Leon, San Francisco del Rincon, Silao, Irapuato, Salamanca, Celaya, Apaseo el Grande and Apaseo el Alto.

[5] Where a 1 in a cell indicates that this municipality is specialized in the branch to which the column corresponds, and a 0 indicates that it is not.

[6] The matrix is symmetrical and the values on the main diagonal are ones because the proximity of each branch to itself is 1.

[7] Three products were considered: grapes, wines and auto parts. When calculating their proximity, a greater proximity would be expected between grapes and wines, closer to 1, than between grapes and auto parts, given that the productive capacities required to produce grapes and wines are more similar.