

## Diversification in the Manufacturing Industry of Ecuador: Grouping Factors by K-means Clustering

Byron Quito<sup>1</sup>, María de la Cruz del Río-Rama<sup>2\*</sup> & Amador Durán-Sánchez<sup>3</sup>

<sup>1</sup>Economics Career, Universidad Nacional de Loja (UNL), 11-01-11 Loja, Ecuador

<sup>2</sup>Business Management and Marketing Department, Faculty of Business Sciences and Tourism, University of Vigo, As Lagoas S/n, 32004 Ourense, Spain

<sup>3</sup>Departamento de Economía Financiera y Contabilidad, Instituto Universitario de Investigación para el Desarrollo Territorial Sostenible (INTERRA), Facultad de Empresa Finanzas y Turismo, Universidad de Extremadura, Cáceres, España

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This study aims to show the state of industrial diversification in manufacturing in Ecuador and to establish clusters that enable to differentiate the state between cantons that share similar industrial characteristics. The three-digit categorization of the International Standard Industrial Classification (ISIC) is used, including a total of 136 sectors in 221 cantons at the national level in 2019. In addition, the Shannon and Simpson indices were calculated as a diversification measure of the manufacturing industry, explicitly allowing us to quantify both the breadth and dominance structure of industrial activities across cantons. These indices, combined with Gross Value Added, schooling and the Environmental Promotion Tax, support the application of a multivariate K-means clustering approach. The method is particularly applicable for distinguishing territorial patterns of industrial structure, as it enables the identification of groups of cantons with similar diversification profiles and economic characteristics. The novelty of this study lies in integrating ecological-based diversity measures with clustering techniques to characterise manufacturing heterogeneity at a sub-national level, an approach not previously applied in the Ecuadorian context. This methodological framework is used to detect the optimal number of clusters, in order to increase the heterogeneity between groups and improve the analyses for each of them. Once the homogeneous clusters were established, the results showed that the cantons of Guayaquil and Quito have a supremacy over the rest of the regions, in terms of diversification of their manufacturing industry. Finally, more than 70% of the cantons do not show significant industrial diversification according to the estimated indices.

**Keywords:** Ecuador, Industrial diversification, Industrial sector, K-means, Manufacture

### Introduction

Industrialization in Latin America is poorly diversified, and is understood as a way to innovate and generate differential income, in addition to an expansion of the technological competences of the sector.<sup>1</sup> In recent decades, there have been no changes in the region's productive structure, based mainly on the exploitation of natural resources, according to the Economic Commission for Latin America and the Caribbean.<sup>2</sup> As a result, the region faces significant difficulties in advancing its industrial development, particularly due to the weak implementation of structural change policies that promote modern and high-productivity sectors. According to the National Institute of Statistics and Censuses (INEC)<sup>3</sup>, manufacturing in Ecuador is a very important sector,

which in 2019 generated 10% of formal jobs and contributed 12.5% of the country's total production.

In relation to this, Sarmiento<sup>4</sup> suggests that the dynamic process of industrial growth and diversification is subject to diminishing returns at the outset, depleting at a higher rate in sectors of lower complexity than in those where complexity is higher. That is why industrial development then allows labour to move from sectors of depleted productivity to sectors of relatively high complexity, which is why the secondary sector of the economy reveals a "staggered increase in productivity with ups and downs".<sup>5</sup> Hence the importance of industrial and technological diversification as a strategy adopted by economies seeking to minimise the risk derived from dependence on one or a few products. However, this decision is not trivial, since it is associated with a series of drawbacks and, therefore, needs to be studied.<sup>6</sup>

\*Author for Correspondence  
E-mail: delrio@uvigo.es

The literature links diversification with the most complex economic structures, as well as an opportunity to improve a region's production levels, making it a valuable pathway in growth processes.<sup>7</sup> To this end, the Shannon and Simpson index allows one to transfer a concept "from an ecosystem diversity in biology" to the economy and its industrial structure, in this case manufacturing. Some of the empirical studies in this line that have incorporated the Shannon or Simpson indices are: Min *et al.*<sup>8</sup>, Deng *et al.*<sup>9</sup> and Zhou & Shi<sup>10</sup> in China; Pacheco *et al.*<sup>11</sup> in Ecuador; Adeola & Evans<sup>12</sup> in Nigeria. These studies focus exclusively on the use of diversification indices as a measure of complexity and how to link them to a sector of the economy. The different applications allow researchers to associate them with measures of interest, such as an economy's growth.

Therefore, this study aims to measure the diversification level in the manufacturing industry in the 221 cantons of Ecuador in 2019 and to identify clusters through diversification indices, the Gross Value Added (GVA), schooling and the Environmental Promotion Tax (EPT). The hypothesis whose objective is to be tested is related to the level of diversification of the canton, i.e., the more diversified a cluster is, the more clustered the factors will be. Therefore, these factors will allow for the identification of clusters with similar characteristics that differ from the rest of the groups.

In order to contribute to the scarce literature related to the diversification of the industrial manufacturing sector in Ecuador, this paper incorporates the construction of indices into the analysis, which enables to observe the diversification level of the sector in the Ecuadorian economy. Identifying clusters among cantons enables to maximise homogeneity within clusters and to differentiate the characteristics of each cluster more precisely. The results provide a picture of the current state of Ecuador's cantons in terms of diversification. Policymakers could also decentralise industrial transformation to the remaining cantons through the already established zoning of provinces. This would enable to incorporate the profits of the industrial sector, related to the high levels of productivity that can be achieved with this sector.

## Data

According to the availability of information, in 2019 a total of 221 cantons or regions of analysis are

considered, which correspond to the second-level administrative divisions in Ecuador. The databases to be analysed were taken from the National Institute of Statistics and Censuses<sup>3</sup>: industrial diversity indices obtained from the Directory of Companies and Establishments (DEE)<sup>13</sup>; the National Survey of Employment, Unemployment and Underemployment (ENEMDU)<sup>14</sup>; the Regional Accounts of the Central Bank<sup>15</sup> and finally, the General Collection Statistics presented by the Internal Revenue Service (SRI).<sup>16</sup>

Regarding the diversity indicators, the Shannon Index and the Simpson Index, these were constructed from 136 categories of manufacturing industries, according to the three-digit ISIC coding. Likewise, the ENEMDU allowed to extract schooling, which is measured in years of the individual's education and averaged by the total sample, taken for each canton. Along the same lines, the Gross Value Added (GVA) is taken from the Regional Accounts, which serves as a proxy for the economic growth of a region, in this case of each canton. Finally, as an environmental measure, the Environmental Promotion Tax (EPT) is considered, which according to the SRI<sup>16</sup> is a tax levied on the environmental pollution produced by the use of motorised land transport vehicles.

In summary, a total of four variables are considered, which are linked to the diversification of manufacturing industries, which is extracted from 136 industry categories. Furthermore, these data are disaggregated into 221 regional units of analysis.

## Results

In Ecuador, according to ECLAC<sup>17</sup>, the manufacturing sector represents an average share of 14.09% of annual GDP, followed by the construction and trade sectors, whose average share of annual GDP was 11.95% and 10.60%, respectively. Despite this, the manufacturing sector has found an important place in the Ecuadorian economy in recent years, behind the extractive and agricultural sectors. Likewise, the Central Bank of Ecuador<sup>18</sup> forecasts that one of the sectors with the highest growth will be manufacturing with 2.74% in 2022, followed by the supply of basic services with 2.29%, which places the sector as a priority when it comes to boosting economic growth in Ecuador. Therefore, potential linkages in relation to further diversification of this industry are important.

Thus, the indices provide a more detailed view of the state of companies and their diversification, considering all categories within this sector. Industry diversity (e.g., the Hirschmann-Herfindahl index) is

usually measured by Simpson's diversity index<sup>19</sup> or Shannon's entropy.<sup>20</sup> These measures are summarised in a single expression of diversity, called the Hill number<sup>21</sup>, with different values for parameter  $q$ , which controls the weight of the species or in this case, industries.

$${}^qD = \left( \sum_i^S p_i^q \right)^{\frac{1}{1-q}} \quad \dots (1)$$

${}^qD$  is the diversity of the degree of the parameter,  $q$  and  $p_i$  is the ratio of the number of individuals to the total number of individuals in the sample.

Simpson's index corresponds to the case,  $q = 2$ , which weighs rare species less and dominant species more than Shannon's entropy ( $q = 1$ ). These two indices were selected in this study and not  $q = 0$ , which corresponds to the number of species present in a sampled group. This exclusion is due to its limited ability to distinguish between station areas: it cannot distinguish two station areas with the same number of subcategories of functions, but with different compositions.

To compare the different station areas, the indices were converted to the effective number or the equivalent number of species equally rare to the group of interest.<sup>22</sup> In addition, the indices were expressed as a percentage ratio to the maximum diversity (26 for both indices in this study: equivalent to the number of subcategories) to facilitate interpretation.

Simpson's diversity-based index is defined below:

$$B_{rl} = \frac{1}{\sum_i p_i^2} \times \frac{1}{\beta_{max}} \quad \dots (2)$$

where,  $\beta_{max}$  is equal to the number of  $m$  individuals.

The Shannon entropy-based index is defined as follows:

$$H_{rl} = \exp\left(\sum_i -p_i \ln p_i\right) \times \frac{1}{H_{max}} \quad \dots (3)$$

where,  $H_{max}$  is also equal to the number of  $m$  individuals. The value varies from 0, which corresponds to a single type of individual, to  $m$ , the number of individuals.

These two indices provide the evidence and contrast to examine the state of manufacturing industries in Ecuador in 2019. Moreover, although the comparison of Shannon and Simpson indices is widely used to describe the structure and dominance of industrial activities, this approach alone does not allow identifying how diversification patterns differ across territories. The Ecuadorian cantons exhibit strong asymmetries in economic size, industrial

composition, schooling and environmental tax burden, which creates substantial heterogeneity that cannot be captured by diversity indices in isolation. For this reason, it becomes necessary to complement the indices with a classification technique capable of grouping cantons into homogeneous categories. The K-means clustering method provides this functionality by integrating diversification measures with other structural variables, allowing us to detect systematic territorial patterns and quantify heterogeneity across regions. This step is essential to understand not only which cantons are more or less diversified, but also how diversification interacts with economic and social characteristics, something that Shannon and Simpson comparisons cannot reveal on their own.

To deal with the heterogeneity present in the diversification levels in each canton, the study adopted the k-means clustering method. Thus, the 221 study cantons were grouped according to economic growth (GVA), schooling, EPT and diversity indices, allowing for the state of the indicators in each group to be compared.

The results obtained are shown in Table 1, corresponding to the 20 cantons with the highest diversity of manufacturing industries, according to the Shannon and Simpson diversity indices. First, in relation to the Shannon index, it determines that most of the cantons with the greatest diversity belong to the coastal region, among these cantons are: Durán, Guayaquil, Quevedo, Machala, Rumiñahui, Orellana, Manta, Mejía, Santa Cruz, Latacunga, La Libertad, Ibarra, Santo Domingo, Esmeraldas, Cuenca, Santa Rosa, Santa Elena, Milagro and Riobamba. Shannon index values above 3 are typically interpreted as "diverse". In other words, cantons with this score have a greater industry diversity, in relation to the 136 sectors considered. Therefore, these 20 cantons have a score above the average of all the cantons, which is 2,424 in a total of 221 cantons. It is noteworthy to observe that cantons such as Guayaquil and Quito have a higher score, which is why they are considered development poles due to their higher concentration in the three sectors.

On the other hand, Simpson's index considers the rarest species as predominant, in the case of this study, manufacturing industries. That is why cantons such as Santa Cruz, Durán, Quevedo, among others, are ranked first in comparison to the Shannon index. However, there is still a predominance of the cantons belonging to the coastal region, especially Guayaquil,

which in comparison to Quito has manufacturing activities that cannot be developed, which are related to category C10 (Processing of food products), especially fish, crustaceans and molluscs. Therefore, it is interesting to note that just as there are cantons where there is a great diversity regarding industries, there are also regions where certain “unique” or “rare” industries predominate, providing a certain advantage over the rest of the cantons.

Analysing a data set globally allows us to identify characteristics that regions or individuals may have in relation to each other. The aim of this is to issue criteria on groups that share a relationship according to the indicators or variables analysed. Therefore, in relation to the multivariate analysis, a K-means

algorithm was applied, which allows economies or regions to be classified into homogeneous groups (cluster) in order to maximise homogeneity (i.e., to minimise variance) within clusters and maximise heterogeneity (i.e., to maximise variance) between clusters (Ward, 1965). This makes the evaluation of the identified groups more efficient. To this end, the four variables were considered, diversity indices, GVA, schooling and EPT for 2019. For each group of variables, 30 tests were conducted to identify the optimal number of clusters to be determined.

The results of the clusters for each of the diversity indices are given in Table 2. In relation to the number of optimal clusters, it can be seen that for both the Simpson and Shannon index, four clusters arise.

Table 1 — 20 cantons with the greatest industrial diversity in Ecuador 2019

Ranking	Canton	Shannon Diversity Index	Ranking	Canton	Simpson's Diversity Index
1	Durán	3.651	1	Santa Cruz	0.944
2	Guayaquil	3.556	2	Durán	0.936
3	Quito	3.468	3	Quevedo	0.921
4	Quevedo	3.401	4	Orellana	0.943
5	Machala	3.394	5	La Libertad	0.933
6	Rumiñahui	3.392	6	Guayaquil	0.919
7	Orellana	3.354	7	Santa Rosa	0.937
8	Manta	3.340	8	Machala	0.929
9	Mejía	3.332	9	Yaguachi	0.925
10	Santa Cruz	3.331	10	Saraguro	0.949
11	Latacunga	3.309	11	Naranjal	0.930
12	La Libertad	3.303	12	Arenillas	0.936
13	Ibarra	3.302	13	Latacunga	0.917
14	Santo Domingo	3.269	14	Manta	0.900
15	Esmeraldas	3.241	15	Nobol	0.924
16	Cuenca	3.221	16	Pedernales	0.899
17	Santa Rosa	3.219	17	Santa Elena	0.936
18	Santa Elena	3.212	18	Yanzatza	0.928
19	Milagro	3.192	19	Playas (General Villamil)	0.914
20	Riobamba	3.193	20	Mejía	0.898
	Promedio total	2.424		Promedio total	0.8477

Note: Diversity indices were calculated according to the three-digit ISIC category, with a total of 136 manufacturing industries

Table 2 — 20 cantons with the greatest industrial diversity in Ecuador 2019

Variables	Cluster				Total
	Cluster 1	Cluster 2	Clúster 3	Cluster 4*	
Number of cantons	21	133	65	2	221
Simpson Diversity Index	0.667	0.874	0.906	0.929	0.876
Gross value added (GVA)	11.986	53.271	234.156	23616.890	61.116
Scholarship	8.402	8.314	9.720	10.904	8.678
Environmental promotion tax (EPT)	50.722	105.929	252.642	41814.130	129.976
Number of cantons	45	112	62	2	221
Shannon Diversity Index	1.5607	2.52675	2.9719	3.5125	2.516
Gross value added (GVA)	16.382	55.804	308.2015	23616.89	61.116
Scholarship	8.276	8.403	9.809	10.904	8.678
Environmental promotion tax (EPT)	52.37468	144.2093	257.7669	41814.13	129.976

Note: GVA and Environmental Tax expressed in thousands of dollars; \* represents the cluster with the best factors

Considering Simpson's index, it can be seen that both clusters 3 and 4 have higher indices than the cantonal average. These same clusters have a group mean well above the cantonal mean. Therefore, there is an accumulation of factors, especially in the two main cantons identified in the fourth cluster, Quito and Guayaquil, which have mean values well above the cantonal average. This is due to the fact that these cantons are currently considered poles of development, with levels that other cantons are unable to reach.

In relation to the second group of clusters, which include the Shannon diversity index, they have similar groupings, especially in the fourth cluster. The same cantons (Quito and Guayaquil) can be identified within it, which implies that these cantons, in addition to having a predominance of diversity with regard to manufacturing industries, also have companies that are considered unique with respect to the rest of the industry. On the other hand, in terms of the Shannon index, there is low diversity in both the first and second clusters, which implies that about 71% of the cantons have below-average diversity. Similarly, it can be seen that compared to the third and fourth clusters, both the EPT and the GVA of the first and second clusters have a lower concentration.

Next, Fig. 1 shows the spatial distribution of the clusters according to the diversity indices. It can be seen that most of the cantons located in the first cluster belong to the Amazon region of Ecuador. In addition, the cantons are intensified in this region when considering the Simpson index. In this regard, it can be observed that around the Quito canton, there are cantons belonging to the first cluster that have low diversity. This shows that there are similarities between the cantons detected in the cluster analysis, i.e., at the territorial level, there are no isolated cantons with the exception of Quito and Guayaquil. On the contrary, there are groupings of regions that share similar characteristics.

By way of summary, Fig. 2 identifies the factors of each cluster from the mean. When considering Shannon, it is observed that cluster four shows the highest characteristics over the rest, high industrial diversity in manufacturing, accompanied by high Gross Value Added (GVA), a high level of schooling and a high Environmental Promotion Tax (EPT). On the other hand, it is interesting to note that the rest of the clusters share a very similar level of GVA and EPT. However, there are important differences in relation to the first cluster (21 cantons), which has the

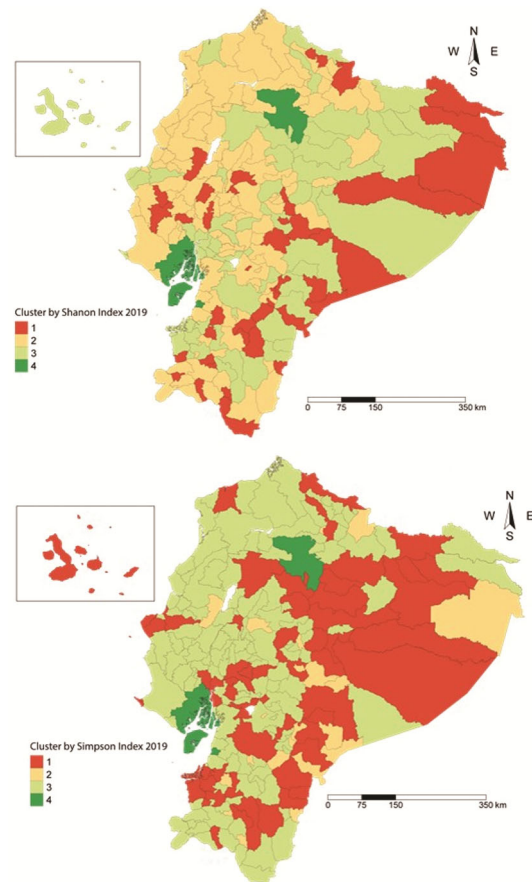


Fig. 1 — Cluster spatial status by industrial diversity indicator; Source: Own elaboration based on the Shannon and Simpson diversity indices

lowest industrial diversity and schooling compared to the rest. Finally, regarding the Shannon index, there are not very significant differences, except for the first factor, where all the clusters, unlike the first one, show close levels of diversity, which is related to the presence of few or unique industries.

## Discussion

The manufacturing activity has represented a major debate in Ecuador over the last two decades, and this related to the numerous attempts to incorporate a change in the productive matrix in the development plans of the governments in power. Regarding the studies, they focus their analysis on the extractive and agricultural sector<sup>23,24</sup>, leaving aside the manufacturing industry and even more so the diversification of this sector. Traditional studies analyse the concentration of sectors, linking concentration to a higher level of growth and accumulation of factors<sup>25,26</sup>, while other studies link it to the specialisation level of each sector.<sup>27</sup>

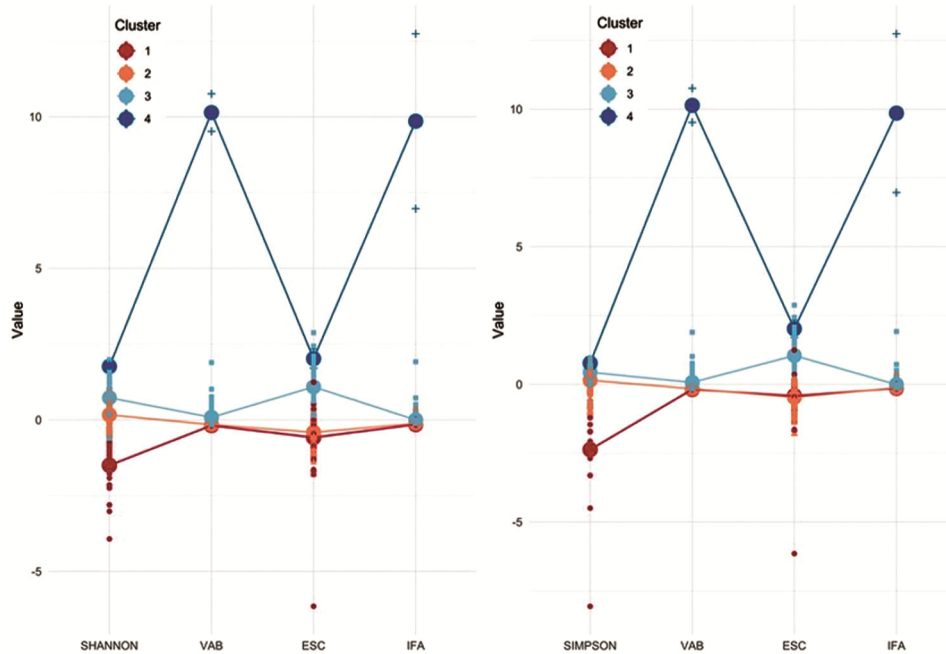


Fig. 2 — Cluster factors by diversity index 2019; Source: Own elaboration based on the Shannon and Simpson diversity indices

Therefore, this study incorporates the diversity index as a diversification indicator of the manufacturing sector in the cantons of Ecuador as an alternative to the existing literature. The results shows that the diversification levels of most of the cantons, more specifically, about 70% show a very low diversification, according to the indices. As a result, two cantons in particular, Quito and Guayaquil, have the highest levels of diversification. Therefore, there is an inefficient allocation of resources among the regions of analysis.<sup>25</sup> Likewise, the formation of clusters allowed us to observe that only these two cantons have unique characteristics (growth, schooling and pollution), which limits the comparison with the rest of the cantons.

However, the interpretation of these findings suggests that diversification in Ecuador is strongly conditioned by structural and historical factors. The concentration of diversified manufacturing activity in Quito and Guayaquil indicates the presence of cumulative causation processes, where economies of scale, human capital accumulation and market access reinforce each other over time. This implies that diversification is not randomly distributed but rather emerges from pre-existing advantages that other cantons are unable to replicate.

Similarly, the importance of this study lies in the scarce literature that links manufacturing diversification with other factors, such as growth,

schooling and finally pollution taxation. In addition, it incorporates a multivariate analysis of K-means clustering, which allows us to make statements about groups of cantons that share characteristics with each other and which differentiate them from the rest of the clusters. This results in an overview of the country's poor industrial policy, which has resulted in a high representation of certain cantons, limiting the emergence of new regions, which promote better levels of productivity and industrial growth.<sup>28</sup>

Furthermore, the clustering results reveal that diversification is systematically associated with higher levels of schooling and economic performance, suggesting that human capital and productive scale are key determinants of industrial variety. This relationship reinforces the hypothesis that cantons with stronger knowledge bases are better positioned to sustain more complex and diverse manufacturing structures. The low EPT levels in less diversified cantons also indicate limited industrial and vehicular activity, which is consistent with a reduced productive base.

Along these same lines, disparities at the regional level can be observed through the spatial state of diversification in the cantons. It can be seen that the Amazonian natural region shows a low diversification among its cantons. The result is related to the high presence of oil extraction activities, which implies a weak development in other industries such as

manufacturing.<sup>29,30</sup> This pattern is consistent with the resource-curse perspective, in which regions dependent on extractive activities tend to show weaker industrial diversification due to institutional, economic and infrastructural biases toward the primary sector. In general, the results are compatible with the current state of Ecuador and its slow industrial level, as opposed to primary and service industries, which have been developed or have a greater presence.

Overall, the inferential analysis suggests that diversification in Ecuador is not only low but also unevenly distributed, reinforcing territorial inequalities and limiting the emergence of new regional growth poles. The findings highlight the need for targeted industrial policies aimed at strengthening human capital, improving productive infrastructure and reducing dependence on extractive activities to enable a more balanced territorial development.

The importance of this study lies in identifying patterns of manufacturing industrial diversification among the 221 cantons of study in 2019 in Ecuador, which will lead to recognising the starting points for formulating public policies located in cantons with less diversification. Meanwhile for cantons with higher diversification levels, mechanisms and instruments must be ensured to facilitate growth projections, which also accumulate factors around the diversification of this sector.

In this regard, there are more than 70% of cantons in Ecuador with relatively low diversification, according to the Shannon and Simpson indices. In addition, among the cantons, four clusters were identified, which have similar characteristics. At this point, the cantons of Quito and Guayaquil maintain their supremacy over the others, by concentrating factors such as growth, environmental tax burden and schooling. This is associated with diversification, which has allowed these two cantons to be identified as a single cluster due to their particular characteristics. Likewise, the cantons of the eastern region show a disparity with respect to the rest of the cantons by showing very low levels of industrial diversification, being located in the clusters with the lowest characteristics.

## Conclusions

It is important to consider the series of evidence found on the state of the diversification of the manufacturing sector, and it is therefore important to formulate policies that promote this sector. Therefore,

in order to reduce the risk related to economies based on extractivism and the use of natural resources, which lose competitiveness in comparative terms at the international level. In this regard, it is necessary to promote projects or programmes that benefit the formation of manufacturing companies with higher technological levels, capable of improving the business fabric and increasing diversification. This study is not without limitations, which are related to the availability of information on other indicators such as financial inclusion, venture capital and public spending at the cantonal level. These indicators could provide evidence to show how the environment can favour the development of new companies in the sector.

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