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The inter-industry structure of the USMCA countries analysis: network GMRIO and data science approach

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Palabras clave: Clustering, USMCA, Added Value, Exports, Data Science, I-O Networks, GVC.

Abstract

The objective of this paper is to analyze the evolution of the inter-industry structure of the USMCA countries in the face of new shoring, driven by the slowdown of neoliberalism, which is in crisis. This has led governments worldwide to reconsider the role of the state in the economy, following the COVID-19 pandemic and rising inequality. Neoliberalism has been associated with weak or stagnant economic growth in many regions, such as Mexico, as well as with greater wealth concentration and job insecurity. The COVID-19 pandemic highlighted the need for strong public intervention in health and the economy, contradicting the premise of minimal state intervention. A paradigm shift towards "economic nationalism" or protectionism is observed, with measures such as the closure of trade borders and increased tariffs resulting from US policies towards China, moving away from unrestricted free trade. Global economic integration has stalled, with declining growth in international trade and a shift towards protecting local industries. The slowdown of neoliberalism is manifested through a "crumbling" of its ideological and political foundation, pushing the global economy towards greater regulation and a rethinking of the free market.
The study methodology is based on the application of input-output network analysis supported by data science. This approach analyzes the underlying characteristics of inter-industry

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clusters in the USMCA countries using the OECD's GMRIO ICIO data for the **period** 1995-2022 (2025 extended edition).
This leads to a classification of industries according to the trajectories and intensities of inter-industry transactions in the three countries. This allows for the identification of underlying global value chains, as well as their domestic and foreign content, represented through an input-output network approach.
Data science methods are used to form clusters. Specifically, the clustering technique is employed, which is an unsupervised learning technique that organizes information into segments based on the distances between observations. Therefore, this method is a powerful tool for identifying trends and making predictions based on the attributes and characteristics of the elements contained in each cluster, meaning that it does not require partitioning the dataset for training and evaluation.
The following clustering algorithms are used: the k-means, other of density (dbscan), and the hierarchical clustering. In all cases, the Python implementation of the sklearn library is used. The results are presented using dendrograms and networks, which confirm strong industrial integration between Mexico and the USA, and to a lesser extent, Canada. These show a cluster of Mexican industries that export a large part of their production, but whose domestic value added is low. These industries maintain a high import component and are incorporated as assembly plants. The US and Canadian industries exhibit clusters of final and intermediate goods with high value added for both domestic consumption and export.
Finally, this work will be very useful for the design of an industrial policy aimed at reconfiguring the industrial structure of the Mexican economy in order to strengthen the Mexican domestic content of dynamic industries in the global value chains of the USMCA before its upcoming review.

1. Introduction.

The North American region is one of the most dynamic in terms of the flow of goods, services, and production factors. This dynamic is the result of the North American Free Trade Agreement (NAFTA), signed in 1994, then reworkwd to USMCA in 2020, which aimed to benefit its member countries through free trade. However, the Mexican economy joined the agreement when its industry had not yet consolidated import substitution; therefore, it faced strong, disadvantageous competition against US and Canadian industries.

Since the treaty entered into force, Mexico's trade with the United States was already predominant, accounting for more than 80\% of Mexico's total exports; nevertheless, this high export activity has not generated a substantial benefit for Mexican industries, as exported goods contain a high imported component while the Domestic Value Added (DVA) remains low (Murillo, 2022). Recent studies indicate that the benefits Mexico obtains are smaller compared to those obtained by the United States and Canada. Murillo (2022) identified, using an input-output model, that Mexico's exports contain a high foreign value added originating from the United States, whereas Gaytán (2022), using the same methodology, concluded that the agreement has had limited effects on the breadth and diversification of trade networks.

Furthermore, Ordóñez (2024) uses a historical-spatial analysis to propose a reconfiguration of global production networks in the North American region. Albarrán and Mejía (2020) found, based on intra-regional trade indicators, that Mexico's integration into the North American region is barely significant, driven mainly by maquiladora industries financed with foreign investment. Méndez-Astudillo and Hernández (2025) performed a clustering analysis of trade among the three USMCA countries.

The lag of the Mexican economy in the context of the USMCA is evident from previous studies; therefore, there is a growing interest in understanding the industrial structure and the causes of such a lag. One probable route is to identify the characteristics acquired by industries that successfully integrate into international trade while incorporating high DVA. Consequently, in this study, a clustering methodology was used to classify industries that, according to their characteristics, achieve greater integration into international trade.

The stated research question is: How are the industries of Mexico, the United States, and Canada classified based on the DVA contained in their exports and their orientation towards the international market? This classification allows for the analysis of the underlying characteristics of industrial clusters that obtain a lesser benefit from commercial exchange.

The results show a cluster of Mexican industries that export a large part of their production, but whose domestic value added is reduced. These are industries that maintain a high imported component and are incorporated as assembly plants. US and Canadian industries, on the other hand, present clusters of final and intermediate goods with high domestic value added destined for both national consumption and export. Currently, the OECD publishes Inter-Country Input-Output (ICIO) tables and Trade in Value-Added (TiVA) indicators for trade among its member countries. This represents a sufficient amount of data to be analyzed using data science techniques, thereby contributing specifically to the trade analysis in the North American region, where the literature is limited. For this analysis, the OECD's ICIO tables (2025 edition) covering the period 1995-2022 were utilized..

2. Methodology

Due to the vast amount of data contained in the OECD ICIO tables, data science methods are used to generate clusters across several dimensions: 1) the relationship between Value Added (VA) and exports, 2) the relationship between intermediate demand and final demand, and 3) the creation of networks using the decomposition method proposed by Wang et al. (2017).

Regarding clustering, several grouping techniques are applied. Clustering is an unsupervised learning technique that organizes information into segments based on the distances between observations; therefore, this method is a powerful tool for identifying trends and making predictions based on the attributes and characteristics of the elements contained in each cluster. The following clustering algorithms were used: 1) k-means, 2) DBSCAN (density-based), and 3) Hierarchical (Ward's method), considering 5 clusters. In all cases, the Python implementation using the scikit-learn (sklearn) library was utilized.

Finally, a representation of the transactions defining the Global Value Chains (GVCs) of the three countries is created; here, total, simple, and complex chains are distinguished according to the method of Wang et al. Initially, a filter was applied to create regional sub-matrices for the USMCA (USA, Mexico, and Canada). This procedure was applied to the entire ICIO series encompassing the 1995-2022 period.

With the objective of analyzing the main trade trajectories among the three countries, dendrograms were created as tree-like graphical representations visualizing the hierarchical clustering of data, showing the proximity and similarity between individuals or clusters. In turn, the clusters are represented in scatter plots to visualize the role played by different sectors; lastly, the most important transactions are represented in networks.

The calculations and representations were performed for all years of the ICIO series; however, for the analysis, only the following key years are taken: 1995 (start of the series), 2008 corresponding to financial crisis, 2016 showing the decline in global growth, and 2022 as the final year of the series. In this presentation, only figures for less spaced periods are shown.

To facilitate the visualization and interpretation of the data science results—such as dendrograms and network graphs—short acronyms were assigned to the selected industries. The next table details the correspondence between the analyzed economic activities from the OECD ICIO database and the acronyms used throughout this paper.

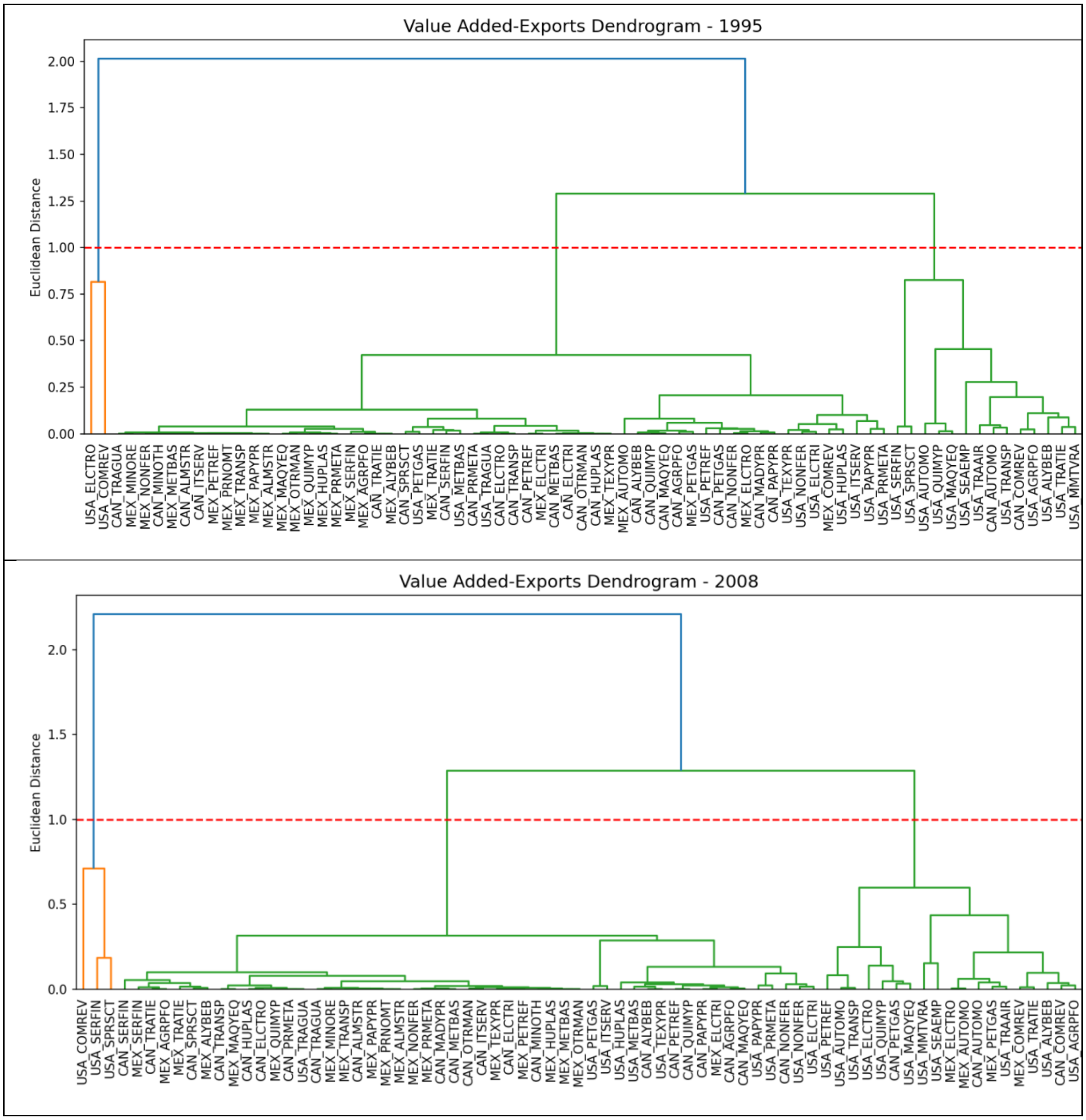
Correspondence table of selected industries with their corresponding acronyms

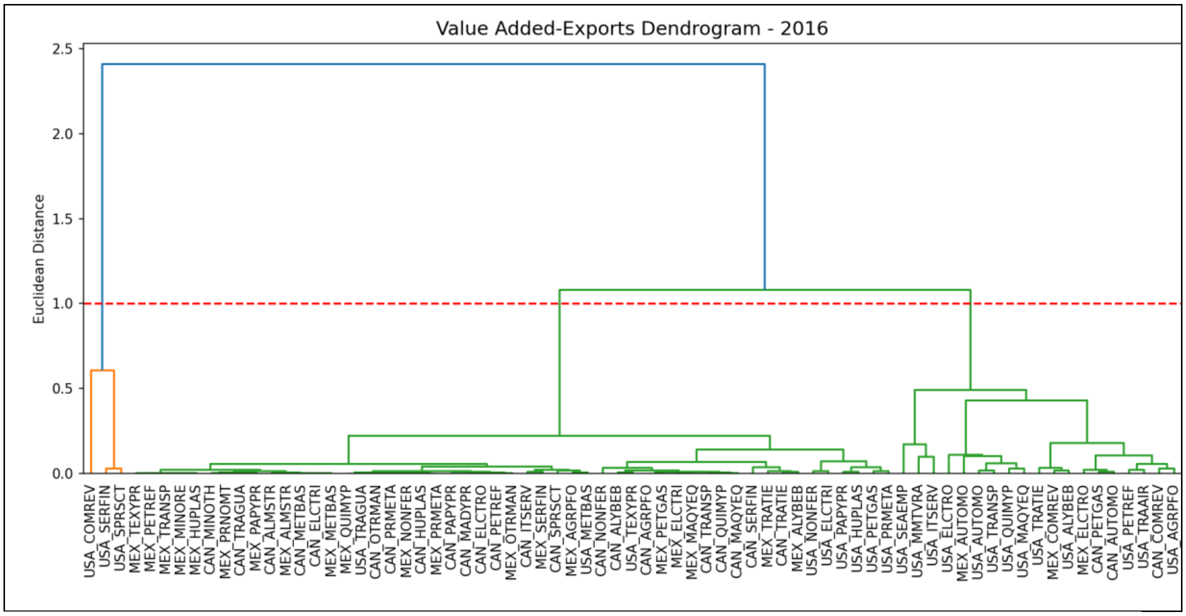
Activity	Acronym	Activity	Acronym
Forestry and logging	FORLOG	Manufacture of motor vehicles, trailers and semi-trailers	AUTOMO
Fishing and aquaculture	PESCAC	Building of ships and boats	OTRTRA
Extraction of crude petroleum and natural gas	PETGAS	Manufacture of other transport equipment	TRANSP
Manufacture of food products; beverages and tobacco products	ALYBEB	Manufacture of furniture and other manufacturing	OTRMAN
Manufacture of textiles, wearing apparel, leather and related products	TEXYPR	Electricity, gas, steam and air conditioning supply	ELEGAS
Manufacture of wood and of products of wood and cork	MADYPR	Water supply; sewerage, waste management and remediation activities	AGUBAS
Manufacture of paper and paper products; Printing and reproduction of media	PAPYPR	Construction	CONSTR
Manufacture of coke and refined petroleum products	PETREF	Wholesale and retail trade; repair of motor vehicles and motorcycles	COMREV
Manufacture of chemicals and chemical products	QUIMYP	Land transport and transport via pipelines	TRATIE
Manufacture of pharmaceutical products and preparations	FARMED	Water transport	TRAGUA
Manufacture of rubber and plastic products	HUPLAS	Air transport	TRAAIR
Manufacture of other non-metallic mineral products	PRNOMT	Warehousing and support activities for transportation	ALMSTR
Manufacture of basic iron and steel	METBAS	Postal and courier activities	POSTME
Manufacture of basic precious and other non-ferrous metals	NONFER	Accommodation and food service activities	HOTYRE
Manufacture of fabricated metal products	PRMETA	Publishing, Motion picture, video, television production and broadcasting	MMTVRA
Manufacture of computer, electronic and optical products	ELCTRO	Telecommunications	TELECO
Manufacture of electrical equipment	ELCTRI	Computer programming and information service activities	ITSERV
Manufacture of machinery and equipment n.e.c.	MAQYEQ		

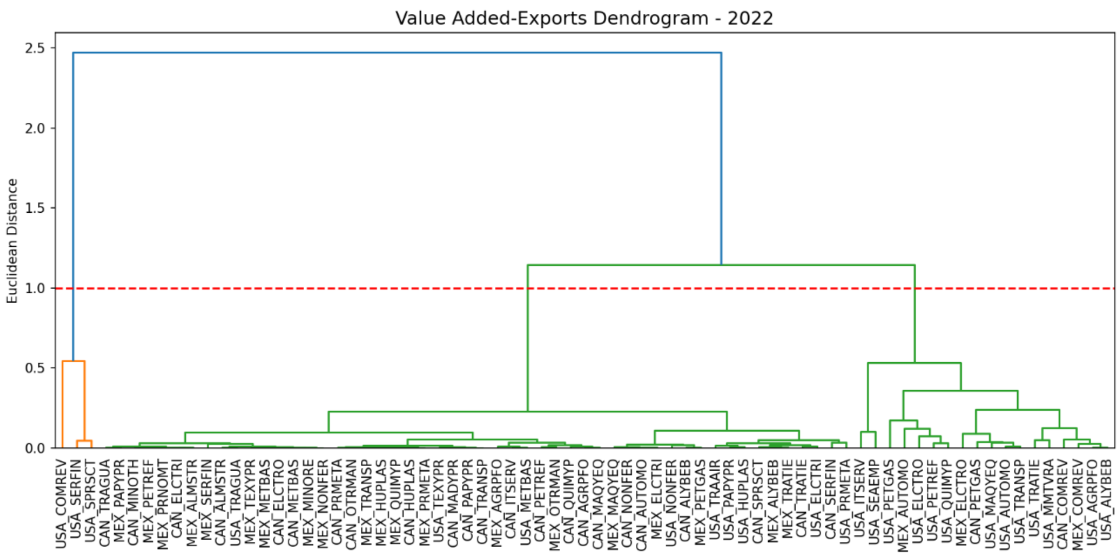
3. Results

3.1 Relationship between Value Added and Exports

The first four dendrograms show the evolution of the relationship between VA and exports for the main USMCA industries, considering the periods 1995, 2008, 2016, and 2022. Here, the great importance of Mexican industries is shown, such as: Automotive, Electronics, and Electrical, which belong to the assembly plant strategy. It can be visualized how these Mexican industries integrate into the cluster with the USA.

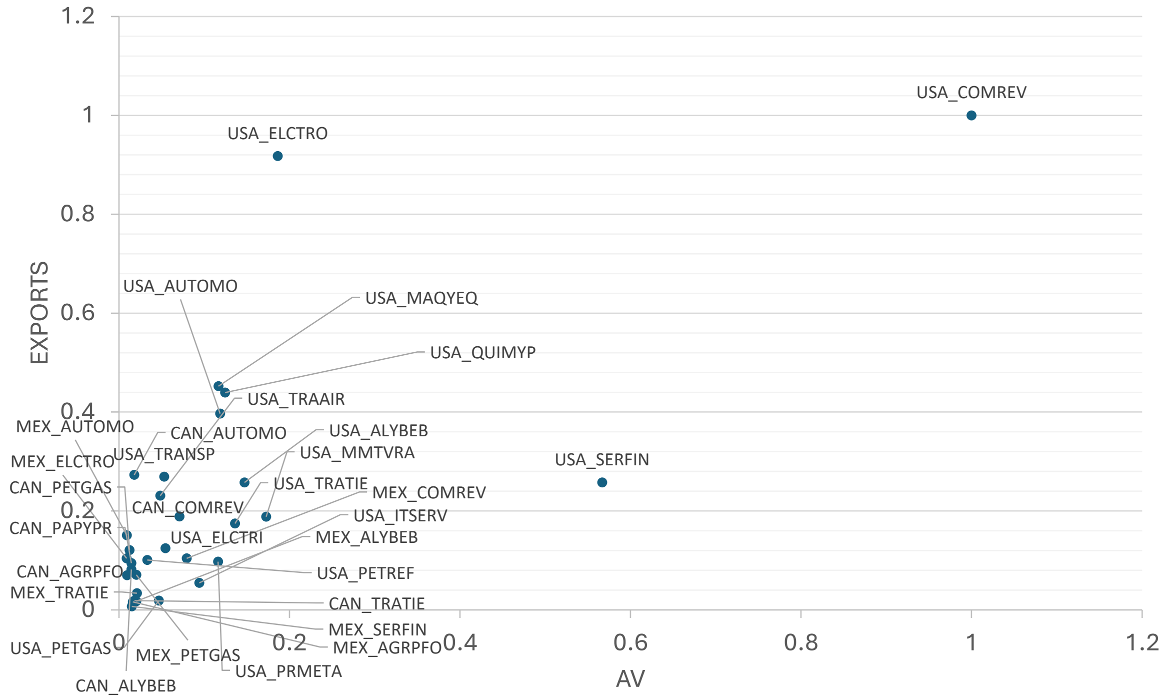

Value Added-Exports Dendrogram - 1995
Euclidean Distance
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
USA_ELCTRO
USA_COMREV
CAN_TRAGUA
MEX_MINORE
MEX_NONFER
CAN_MINOTH
MEX_METBAS
CAN_ALMSTR
CAN_ITSERV
MEX_PETREF
MEX_PRNOMT
MEX_TRANSP
MEX_PAPYPR
MEX_ALMSTR
MEX_MAQYEQ
MEX_OTRMAN
MEX_QUIMYP
MEX_HUPLAS
MEX_PRMETA
MEX_SERFIN
MEX_AGRPFO
CAN_TRATIE
MEX_ALYBEB
CAN_SPRSCT
USA_PETGAS
MEX_TRATIE
CAN_SERFIN
USA_METBAS
CAN_PRMETA
USA_TRAGUA
CAN_ELCTRO
CAN_TRANSP
CAN_PETREF
MEX_ELCTRI
CAN_METBAS
CAN_ELCTRI
CAN_OTRMAN
CAN_HUPLAS
MEX_TEXYPR
MEX_AUTOMO
CAN_ALYBEB
CAN_QUIMYP
CAN_MAQYEQ
CAN_AGRPFO
MEX_PETGAS
USA_PETREF
CAN_PETGAS
CAN_NONFER
MEX_ELCTRO
CAN_MADYPR
CAN_PAPYPR
USA_TEXYPR
USA_NONFER
USA_ELCTRI
MEX_COMREV
USA_HUPLAS
USA_ITSERV
USA_PAPYPR
USA_PRMETA
USA_SERFIN
USA_SPRSCT
USA_AUTOMO
USA_QUIMYP
USA_MAQYEQ
USA_SEAEMP
USA_TRAAIR
CAN_AUTOMO
USA_TRANSP
CAN_COMREV
USA_AGRPFO
USA_ALYBEB
USA_TRATIE
USA_MMTVRA
Value Added-Exports Dendrogram - 2008
Euclidean Distance
2.0
1.5
1.0
0.5
0.0
USA_COMREV
USA_SERFIN
USA_SPRSCT
CAN_SERFIN
MEX_SERFIN
CAN_TRATIE
MEX_AGRPFO
MEX_TRATIE
CAN_SPRSCT
MEX_ALYBEB
CAN_TRANSP
MEX_MAQYEQ
CAN_HUPLAS
CAN_ELCTRO
MEX_QUIMYP
CAN_PRMETA
USA_TRAGUA
CAN_TRAGUA
MEX_MINORE
MEX_TRANSP
CAN_ALMSTR
MEX_PAPYPR
MEX_PRNOMT
MEX_ALMSTR
MEX_NONFER
MEX_PRMETA
CAN_MADYPR
CAN_METBAS
CAN_OTRMAN
CAN_ITSERV
MEX_TEXYPR
CAN_ELCTRI
MEX_PETREF
CAN_MINOTH
MEX_HUPLAS
MEX_METBAS
MEX_OTRMAN
USA_PETGAS
USA_ITSERV
USA_HUPLAS
USA_METBAS
CAN_ALYBEB
USA_TEXYPR
CAN_PETREF
CAN_QUIMYP
CAN_PAPYPR
MEX_ELCTRI
CAN_AGRPFO
CAN_MAQYEQ
USA_PAPYPR
USA_PRMETA
CAN_NONFER
USA_NONFER
USA_ELCTRI
USA_PETREF
USA_AUTOMO
USA_TRANSP
USA_ELCTRO
USA_QUIMYP
CAN_PETGAS
USA_MAQYEQ
USA_MMTVRA
USA_SEAEMP
MEX_ELCTRO
MEX_AUTOMO
CAN_AUTOMO
MEX_PETGAS
USA_TRAAIR
MEX_COMREV
USA_TRATIE
USA_ALYBEB
CAN_COMREV
USA_AGRPFO


Value Added-Exports Dendrogram - 2016
Euclidean Distance
0.0
0.5
1.0
1.5
2.0
2.5
USA_COMREV
USA_SERFIN
USA_SPRSCT
MEX_TEXYPR
MEX_PETREF
MEX_TRANSP
MEX_MINORE
MEX_HUPLAS
CAN_MINOTH
MEX_PRNOMT
CAN_TRAGUA
MEX_PAPYPR
CAN_ALMSTR
MEX_ALMSTR
CAN_METBAS
CAN_ELCTRI
MEX_METBAS
MEX_QUIMYP
USA_TRAGUA
CAN_OTRMAN
CAN_PRMETA
MEX_NONFER
CAN_HUPLAS
MEX_PRMETA
CAN_PAPYPR
CAN_MADYPR
CAN_ELCTRO
CAN_PETREF
MEX_OTRMAN
CAN_ITSERV
MEX_SERFIN
CAN_SPRSCT
MEX_AGRPFO
USA_METBAS
CAN_NONFER
CAN_ALYBEB
USA_TEXYPR
CAN_AGRPFO
MEX_PETGAS
MEX_ELCTRI
MEX_MAQYEQ
CAN_TRANSP
CAN_QUIMYP
CAN_MAQYEQ
CAN_SERFIN
MEX_TRATIE
CAN_TRATIE
MEX_ALYBEB
USA_NONFER
USA_ELCTRI
USA_PAPYPR
USA_HUPLAS
USA_PETGAS
USA_PRMETA
USA_SEAEMP
USA_MMTVRA
USA_ITSERV
USA_ELCTRO
MEX_AUTOMO
USA_AUTOMO
USA_TRANSP
USA_QUIMYP
USA_MAQYEQ
USA_TRATIE
MEX_COMREV
USA_ALYBEB
MEX_ELCTRO
CAN_PETGAS
CAN_AUTOMO
USA_PETREF
USA_TRAAIR
CAN_COMREV
USA_AGRPFO

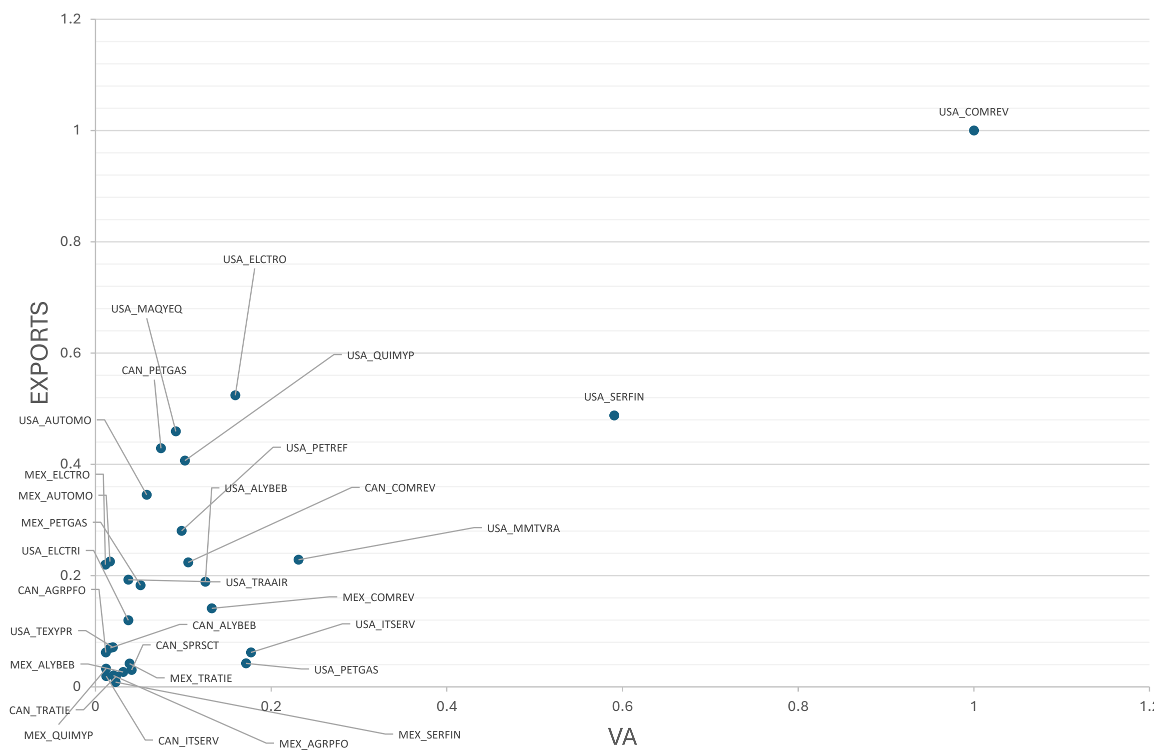

Value Added-Exports Dendrogram - 2022
Euclidean Distance
0.0
0.5
1.0
1.5
2.0
2.5
USA_COMREV
USA_SERFIN
USA_SPRSCT
CAN_TRAGUA
MEX_PAPYPR
CAN_MINOTH
MEX_PETREF
MEX_PRNOMT
CAN_ELCTRI
MEX_ALMSTR
MEX_SERFIN
CAN_ALMSTR
USA_TRAGUA
MEX_TEXYPR
MEX_METBAS
CAN_ELCTRO
CAN_METBAS
MEX_MINORE
MEX_NONFER
CAN_PRMETA
CAN_OTRMAN
MEX_TRANSP
MEX_HUPLAS
MEX_QUIMYP
CAN_HUPLAS
MEX_PRMETA
USA_TEXYPR
CAN_MADYPR
CAN_PAPYPR
CAN_TRANSP
MEX_AGRPFO
CAN_ITSERV
USA_METBAS
CAN_PETREF
MEX_OTRMAN
CAN_QUIMYP
CAN_AGRPFO
CAN_MAQYEQ
MEX_MAQYEQ
CAN_NONFER
CAN_AUTOMO
MEX_ELCTRI
USA_NONFER
CAN_ALYBEB
MEX_PETGAS
USA_TRAAIR
USA_PAPYPR
USA_HUPLAS
CAN_SPRSCT
MEX_ALYBEB
MEX_TRATIE
CAN_TRATIE
USA_ELCTRI
CAN_SERFIN
USA_PRMETA
USA_ITSERV
USA_SEAEMP
USA_PETGAS
MEX_AUTOMO
USA_ELCTRO
USA_PETREF
USA_QUIMYP
MEX_ELCTRO
CAN_PETGAS
USA_MAQYEQ
USA_AUTOMO
USA_TRANSP
USA_TRATIE
USA_MMTVRA
CAN_COMREV
MEX_COMREV
USA_AGRPFO
USA_ALYBEB

The graphs corresponding to these four dendrograms are shown below, with the aim of visualizing the relative positions of these industries.

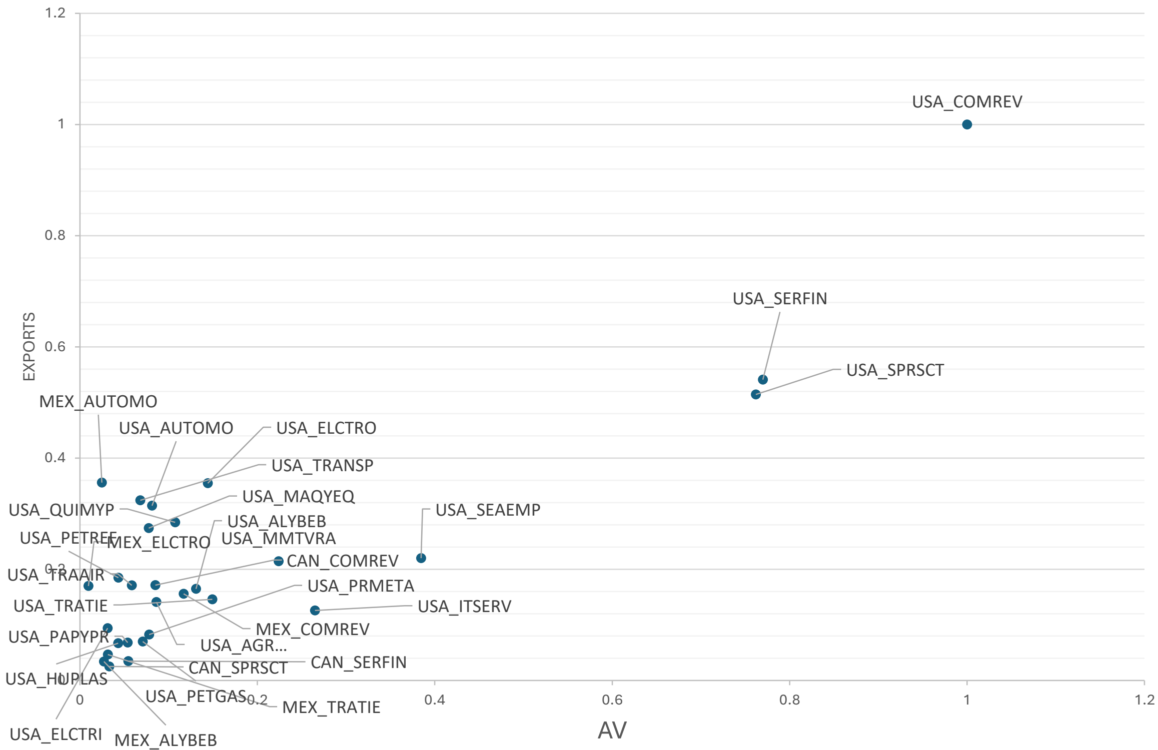
Graph 1: Clustering (Ward). UMSCA: USA, México y Canadá, 1995. Added Value vs. Exports. Country of origin-Sector-Country of destination.



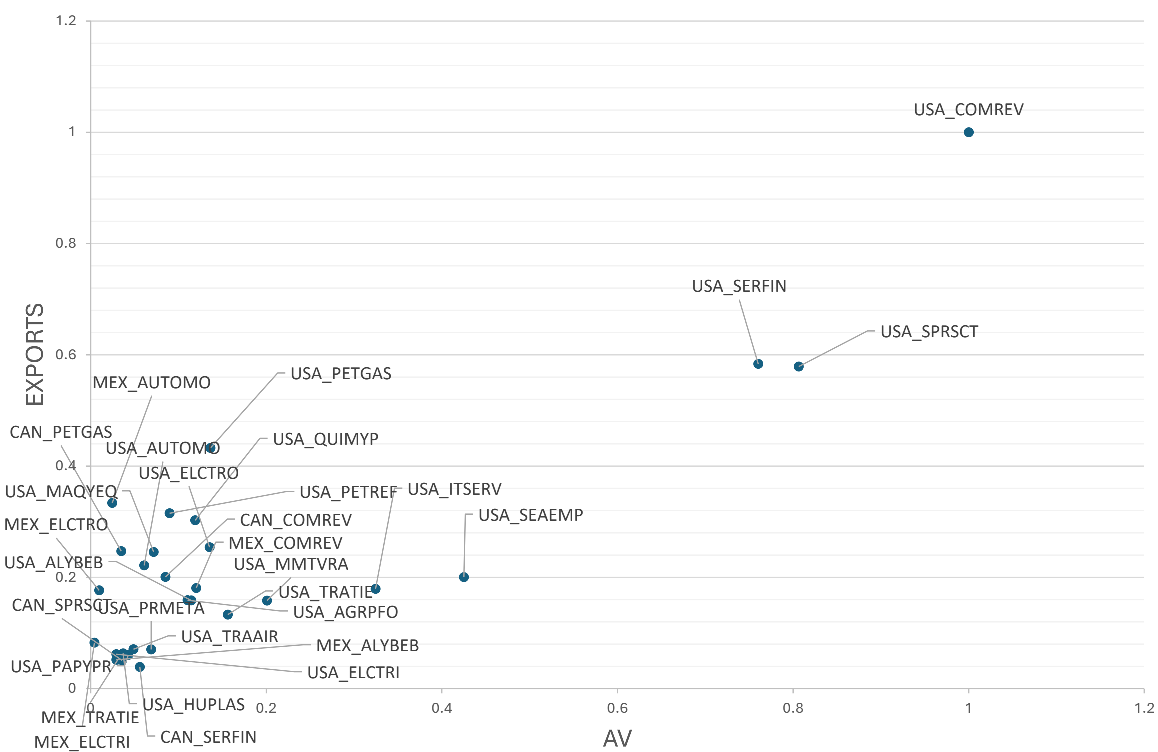
Graph 2: Clustering (Ward). UMSCA: USA, México y Canadá, 2008. Added Value vs. Exports. Country of origin-Sector-Country of destination.



Graph 3: Clustering (Ward). UMSCA: USA, México y Canadá, 2016. Added Value vs. Exports. Country of origin-Sector-Country of destination.



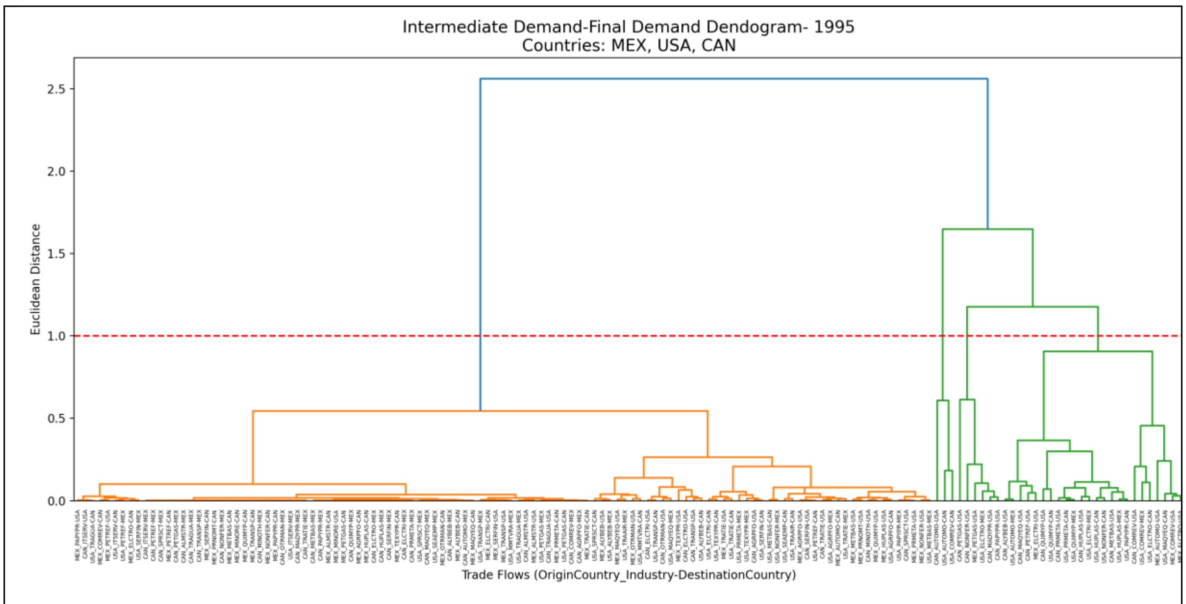
Graph 4: Clustering (Ward). UMSCA: USA, México y Canadá, 2022. Added Value vs. Exports. Country of origin-Sector-Country of destination.

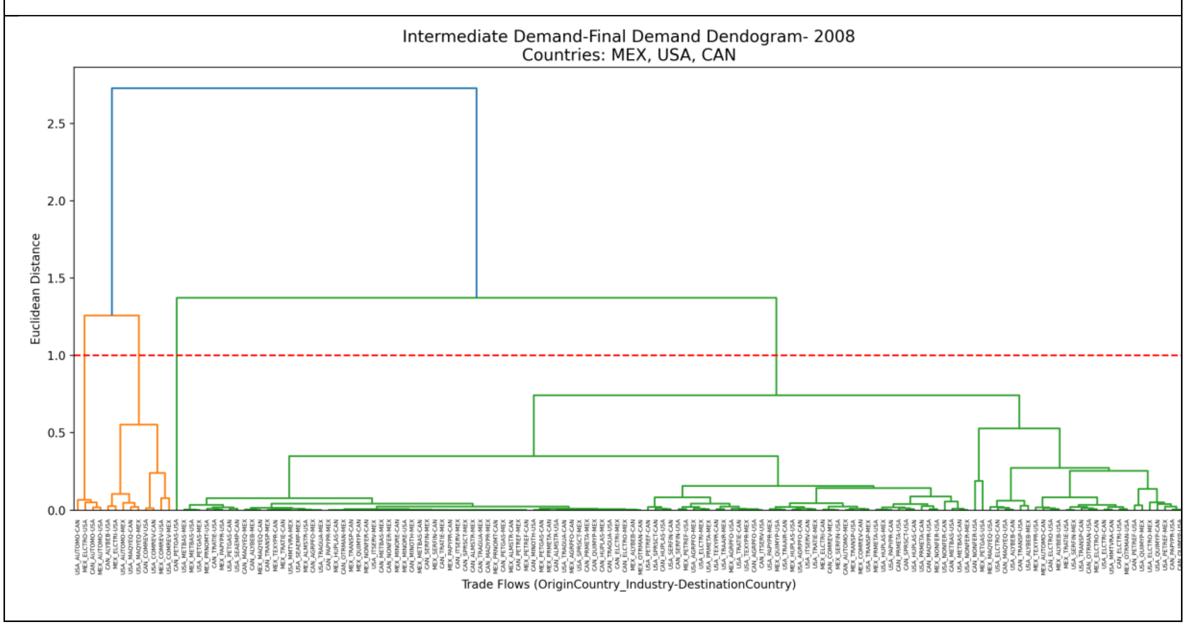


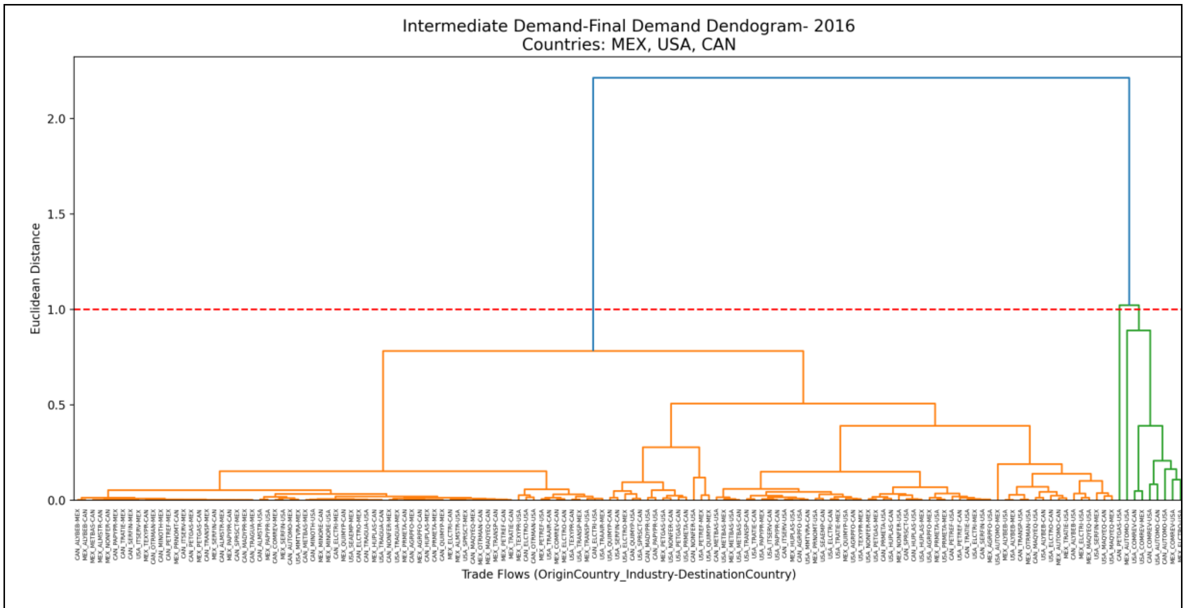
These graphs show how the most dynamic Mexican industries, although exhibiting an export-oriented approach (Automotive, Electronics, and Electrical), present a reduced Value Added (VA). On the other hand, the trade industries stand out across all three countries.

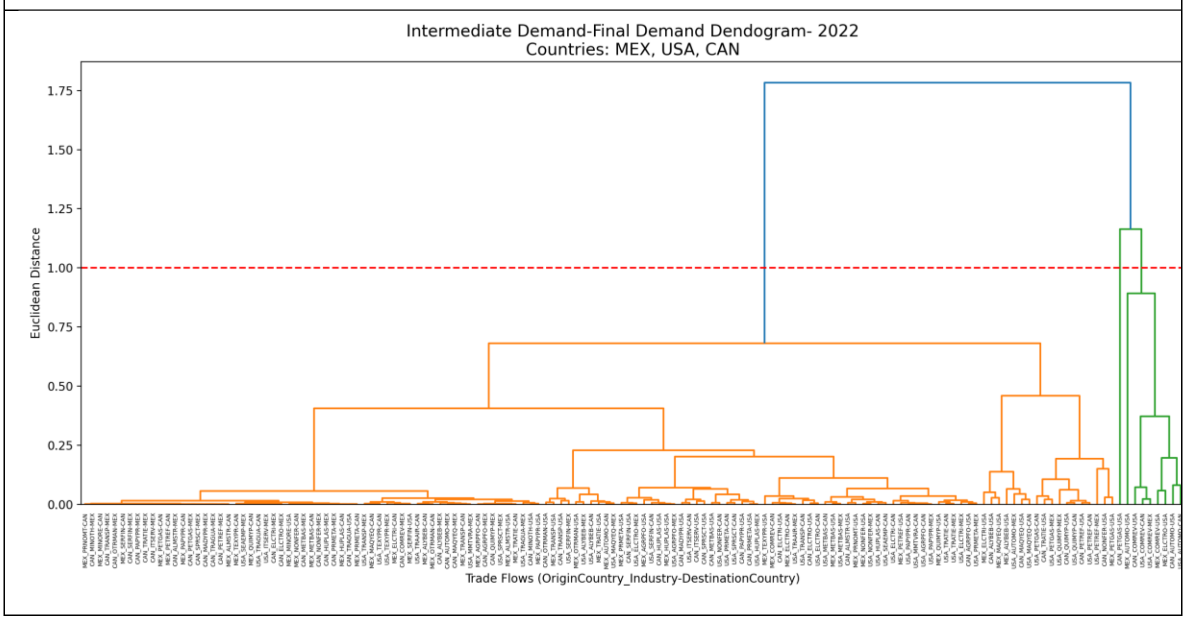
3.2. Relationship of USMCA inter-industry trade in intermediate and final godos.

In this section, we present the results of the USMCA inter-industry trade regarding the combination of intermediate and final goods. First, the dendrograms for the four periods considered (1995, 2008, 2016, and 2022) are presented, followed by their corresponding graphs.





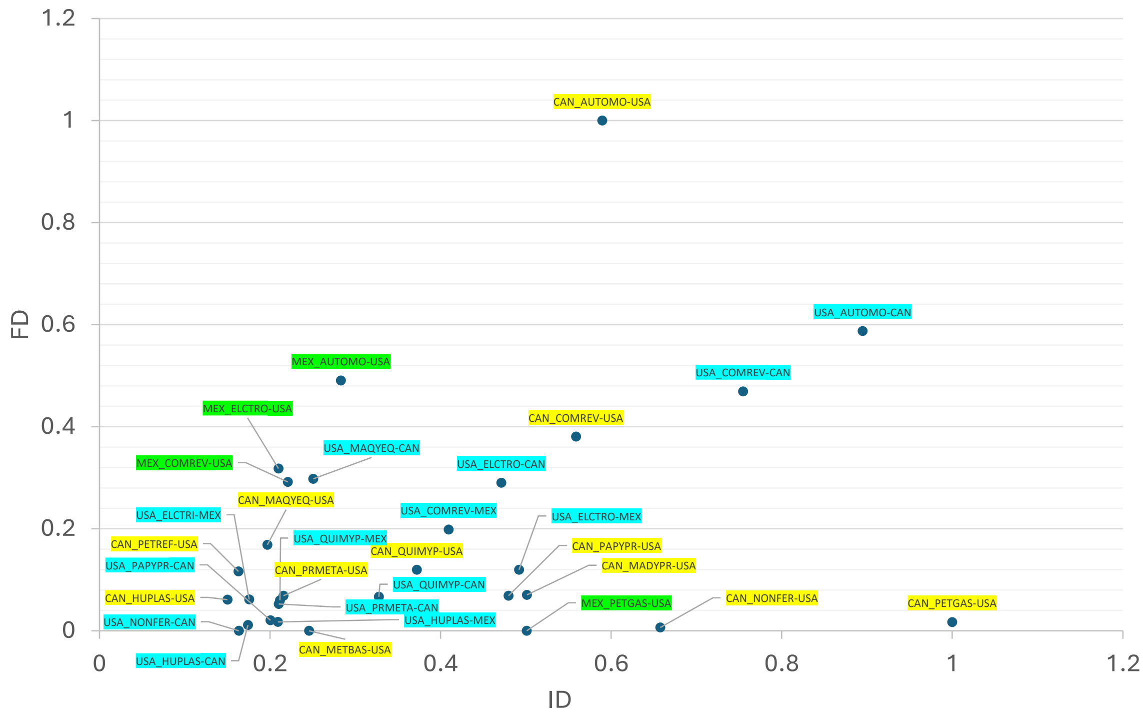




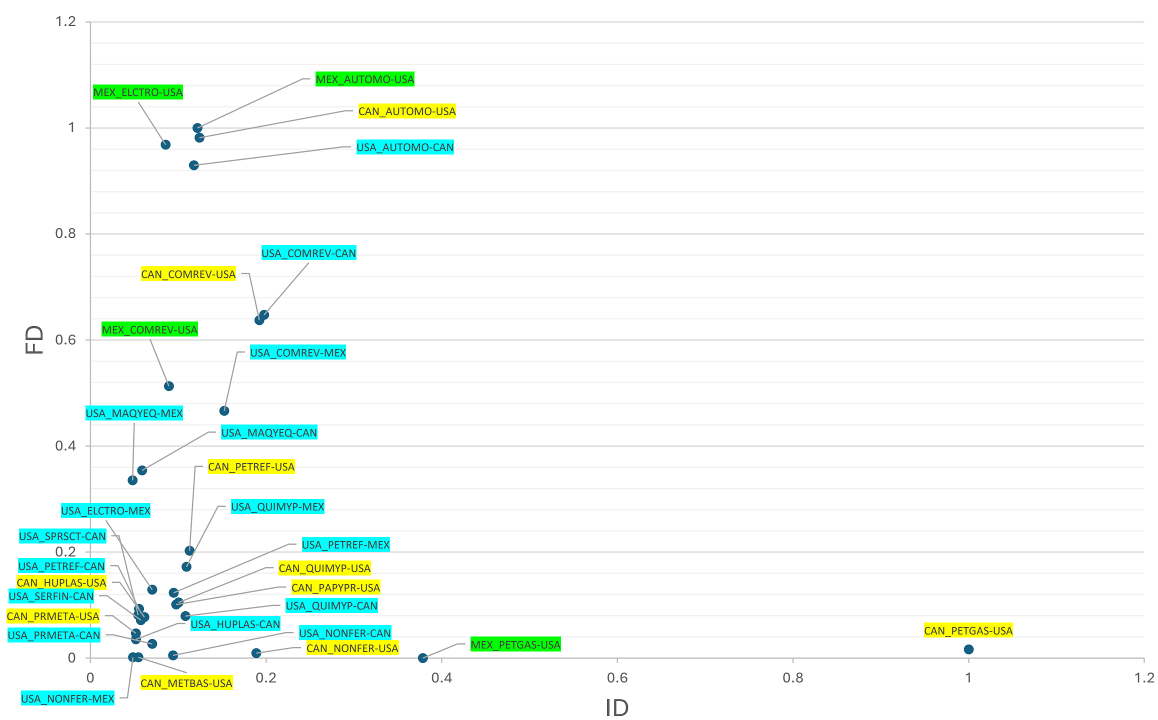
It can be observed how a set of Mexican manufacturing industries integrate into clusters with industries from the US and Canada. However, it is evident that the most dynamic industries, such as the automotive, electronics, and electrical sectors, are those that integrate most robustly.

Next, we present the graphs of the industries originating intermediate demand destined for final demand, which detail the results of the dendrograms.

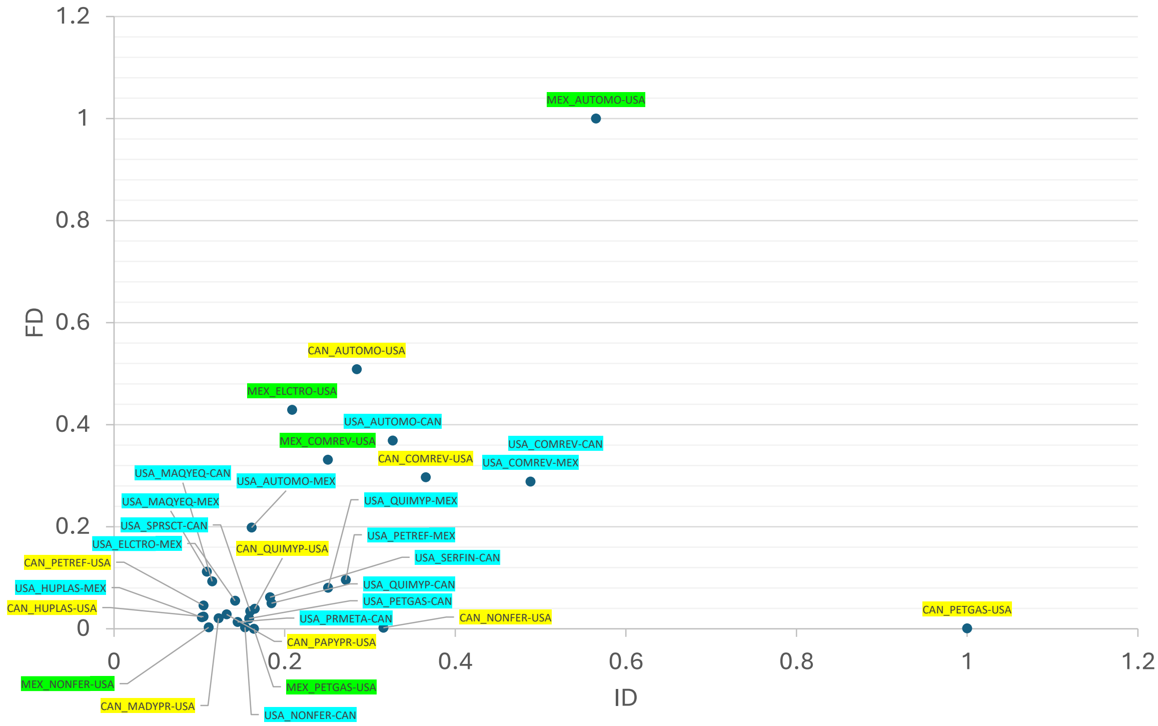
Graph 5: Hierarchical cluster (Ward). UMSCA: USA, México y Canadá, 1995. Intermediate Demand vs. Final Demand. Country of origin-Sector-Country of destination.



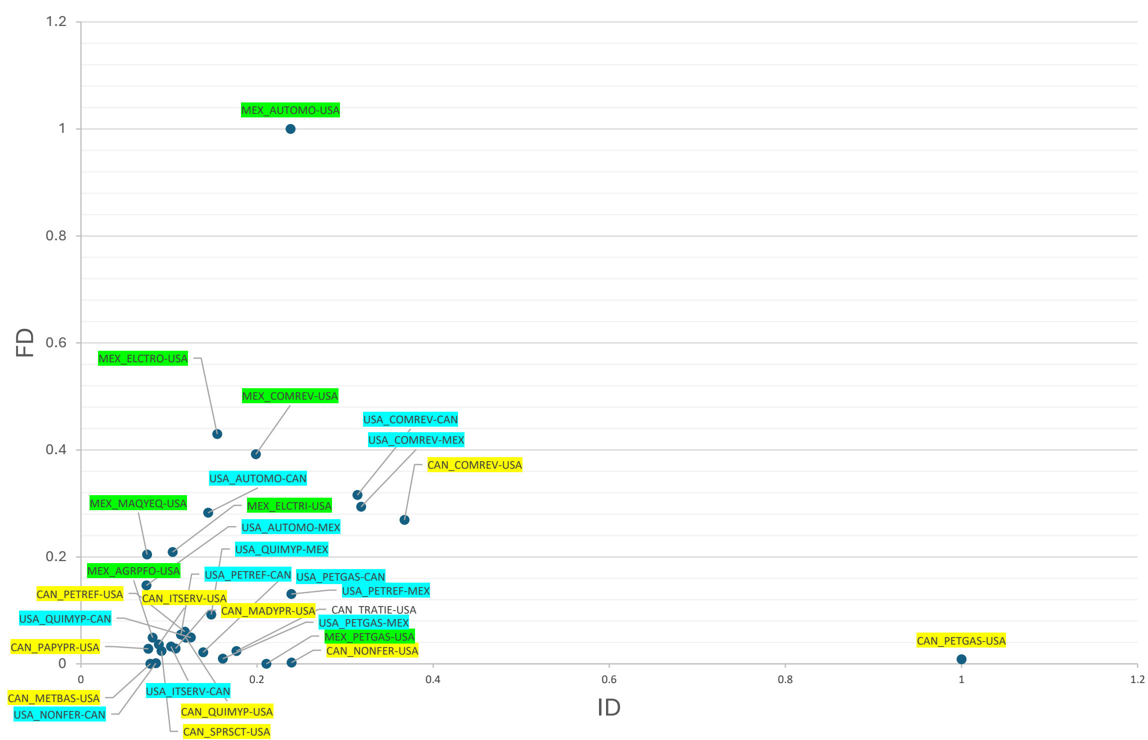
Graph 3: Hierarchical cluster (Ward). UMSCA: USA, México y Canadá, 2008. Intermediate Demand vs. Final Demand. Country of origin-Sector-Country of destination.



Graph 7: Hierarchical cluster (Ward). UMSCA: USA, México y Canadá, 2016. Intermediate Demand vs. Final Demand. Country of origin-Sector-Country of destination.



Graph 8: Hierarchical cluster (Ward). UMSCA: USA, México y Canadá, 2022. Intermediate Demand vs. Final Demand. Country of origin-Sector-Country of destination.



The graphs illustrate how dynamic Mexican industries (Automotive, Electrical, and Electronics) have positioned themselves as key suppliers to the US and Canada. These industries are significant in their relationship with Global Value Chains (GVCs) and have made progress within them; however, this advancement has been limited due to the absence of a robust industrial policy. The importance of intra-regional trade and sectors linked to oil extraction and derivatives is also noteworthy.

3.3. Inter-industry trade network of the USMCA countries for the main industries considered.

Below, we present the networks for the selected industries of the USMCA countries—both among themselves and with China and Japan—to observe the shifts in global hegemony that have established China as a leading global supplier amidst the relative decline of the US and Japan.

The networks were constructed based on the decomposition framework proposed by Wang et al. (2017), which consists of the following approach.

Given the GMRIO solution based on the ICIO partitioned into domestic (D) and foreign (F) components for both intermediate and final demand, we have:

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} a_{11}^D x_1 & 0 & 0 \\ 0 & a_{22}^D x_2 & 0 \\ 0 & 0 & a_{33}^D x_3 \end{bmatrix} + \begin{bmatrix} 0 & a_{12}^F x_2 & a_{13}^F x_3 \\ a_{21}^F x_1 & 0 & a_{23}^F x_3 \\ a_{31}^F x_1 & a_{32}^F x_2 & 0 \end{bmatrix} + \begin{bmatrix} y_{11}^D & 0 & 0 \\ 0 & y_{22}^D & 0 \\ 0 & 0 & y_{33}^D \end{bmatrix} + \begin{bmatrix} 0 & y_{12}^F & y_{13}^F \\ y_{21}^F & 0 & y_{11}^F \\ y_{31}^F & y_{11}^F & 0 \end{bmatrix}$$

The following system of matrix equations is obtained:

$$X = A^D X + A^F X + Y^D + Y^F$$

Where:

$$X = B^T Y^T$$

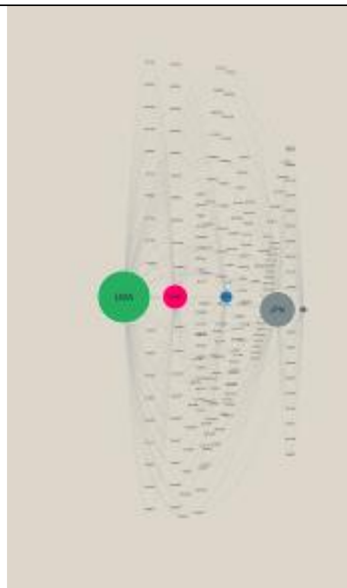
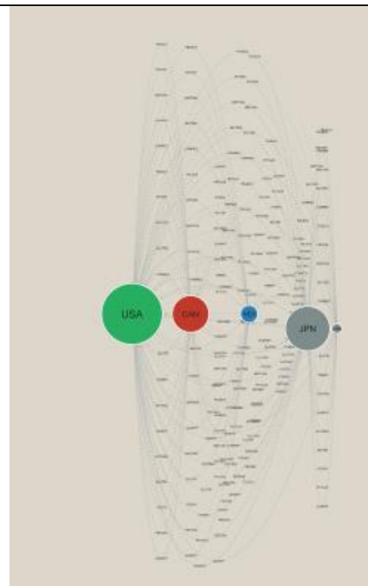
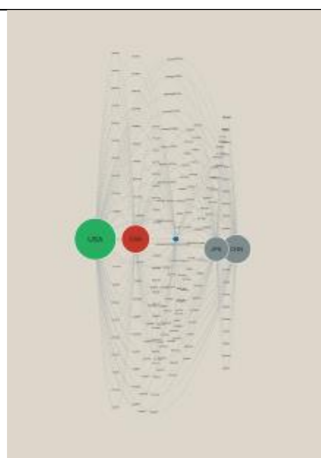
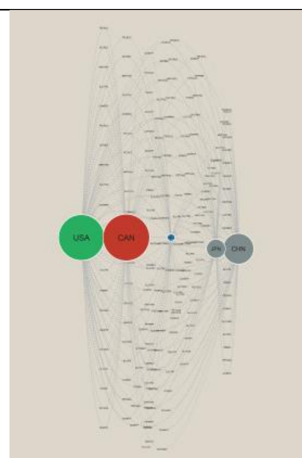
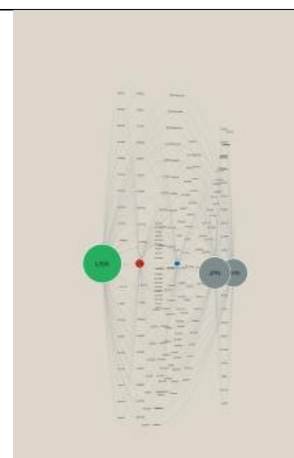
The solution based on the domestic inverse results in:

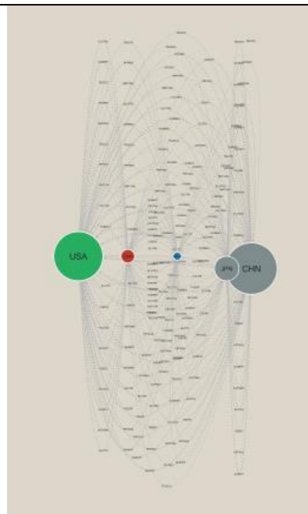
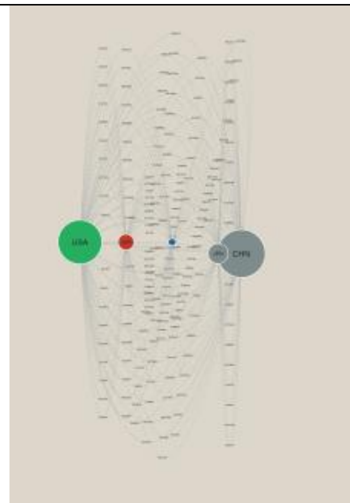
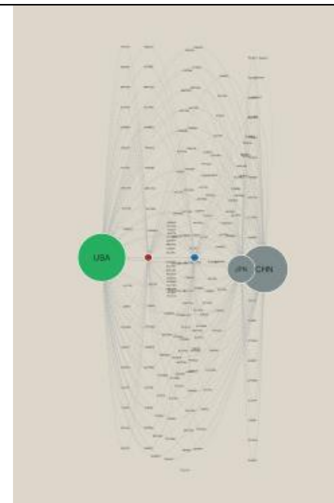
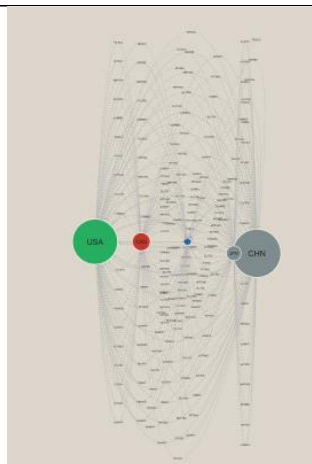
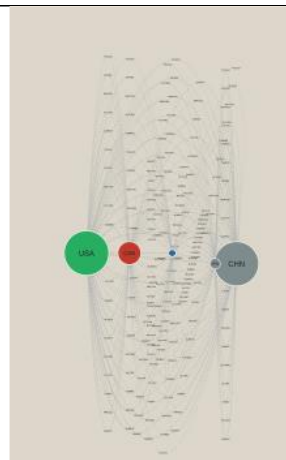
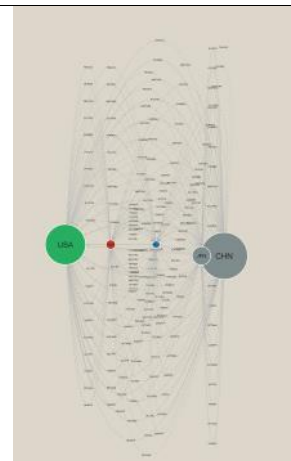
$$X = B^D Y^D + B^D Y^F + B^D A^F B^T Y^T$$

The first term ($B^D Y^D$) is interpreted as a solution for intermediate demand as a function of the domestic Leontief inverse (i.e., without considering imports); the second term ($B^D Y^F$) is a solution for foreign final demand as a function of the domestic Leontief inverse that excludes imports; and the third term contains the solution for interregional trade through the foreign input matrix, which serves as the basis for calculating global value chains, considered here as total GVCs. The third term ($B^D A^F B^T Y^T$) represents total global value chains, which can be decomposed into simple and complex global value chains as follows:

$$B^D A^F B^T Y^T = B^D A^F B^D Y^D + [B^D A^F B^T Y^T - B^D A^F B^D Y^D]$$

Where $(B^D A^F B^D Y^D)$ represents simple global value chains, indicating a single border crossing, and $[B^D A^F B^T Y^T - B^D A^F B^D Y^D]$ represents complex value chains, where inputs cross borders multiple times. In this study, we report the total, simple, and complex networks corresponding to the USMCA countries, including China and Japan, to verify the shift in global hegemony driven by the most dynamic industries.

	TOTAL GVC	SIMPLE CGV	COMPLEX CGV
1995			
2008			

2016			
2022			

For the selected years (1995, 2008, 2016, and 2022), the networks illustrate the relative displacement by China of the US and Japanese hegemony regarding the supply to the most dynamic industries of the USMCA.

4. Conclusions

The results reveal a cluster of Mexican industries that exports a large portion of its production, yet its domestic value added remains low. These industries maintain a high imported component and integrate primarily as assembly operations. Conversely, US and Canadian industries exhibit clusters of final and intermediate goods with high domestic value added destined for both domestic consumption and export.

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