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DESCRIBING COSTA RICA'S ECONOMIC NETWORK

DESCRIPCIÓN DE LA RED ECONÓMICA DE COSTA RICA

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ABSTRACT

This study establishes the foundation for viewing the Costa Rican economy as a complex system and provide policymakers with a robust analytical framework to enhance economic performance. To tackle the initial challenge of understanding the economy as an interconnected structure, we analyze the economic relationships among the products within Costa Rica's Input-Output Matrix. Through this analysis, we identify the best positioned actors, both individually and as part of network subgroups. Understanding the positioning of these actors within the network is crucial to comprehend how their roles can be improved by accessing different network regions and establishing relations with other actors. Our findings reveal the existence of actors that have access to different regions within the network, allowing them to serve as bridges between economic sectors. Consequently, strengthening these well-positioned actors through targeted policies can yield simultaneous benefits for both network subgroups and the overall economy.

KEYWORDS: ECONOMIC NETWORK, ECONOMIC METHODOLOGY, QUANTITATIVE METHODS, INPUT-OUTPUT MODEL, COMPLEX NETWORKS.
JEL CLASSIFICATION: C02, C18, C31, C67.

RESUMEN

Este estudio establece las bases para analizar la economía costarricense como un sistema complejo, al mismo tiempo que proporciona a los responsables de la formulación de políticas un sólido marco analítico para mejorar el rendimiento económico. Para abordar este primer desafío de comprender la economía como una estructura interrelacionada, se examinan las relaciones económicas de los productos en la Matriz Insumo-Producto del país. Se identifican los actores mejor ubicados, tanto individualmente como en subgrupos de la red. Su ubicación en la red es clave para comprender cómo se pueden mejorar sus roles al acceder a diferentes regiones de la red y establecer relaciones con otros actores. Los hallazgos indican que existen actores que acceden a diferentes regiones en la red, lo que les permite actuar como enlaces entre los sectores económicos. Por lo tanto, fortalecer a estos actores mejor ubicados mediante políticas específicas puede generar beneficios simultáneos tanto para los subgrupos de la red como para la economía en su conjunto.

PALABRAS CLAVE: RED ECONÓMICA, METODOLOGÍA ECONÓMICA, MÉTODOS CUANTITATIVOS, MODELO INPUT-OUTPUT, REDES COMPLEJAS.
CLASIFICACIÓN JEL: C02, C18, C31, C67.

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I. INTRODUCTION

The focus of the present study is to analyze the system of interrelations within Costa Rica's economy. Despite being recognized as the most dynamic economy in Central America and the Caribbean (Programa Estado de la Nación, 2016) and one of the most stable in Latin America, Costa Rica remains a small country with a relatively modest economy compared to larger economies like Brazil and Mexico. Consequently, studying Costa Rica's economy as a network offers a unique opportunity to gain valuable insights. In this study, we employ the Input-Output Matrix (I-O Matrix) to examine the structural characteristics of Costa Rica's economic network.

The application of network analysis methods allows us to explore the relationships within the economy and estimate parameters that reveal underlying structural patterns and identify key economic actors that contribute to the functioning of Costa Rica's economy.

Previous studies have successfully applied the I-O Matrix and network techniques to analyze the economic dynamics of various countries. Lantner and Carluer (2004) investigated regional interconnectedness using input-output tables for the case of France. To achieve this, they employed a weighted graph and utilized matrix theory approaches. In addition, Blöchl et al. (2011) explored the I-O Matrix of several European countries, while Carvalho (2014) analyzed the potential diffusion of economic micro-shocks within the I-O Matrix network of the United States of America (USA). Cerina et al. (2015) examined the interconnections between economic sectors in major global economies, highlighting the dense and asymmetric linkages exhibited by these economies.

Leveraging the World Input-Output Database (WIOD), Bartesaghi et al. (2022) employ a multilayer approach to examine the mesoscale structure and properties of the global input-output network. They identify distinct international communities characterized by more intensive trading between countries. Additionally, Xu and Liang (2019) employed the World Input-Output Database (WIOD) to analyze the structure of the Input-Output (I-O) network. In their study, they utilized network centrality and network group analysis to identify the most prominent actor in the network.

In the same vein, García-Muñiz et al. (2008) employ network theory to discern key sectors within the economic system. Given that analysis solely based on unweighted networks leads to the loss of relational information, the authors developed weighted measures to identify economic sectors that wield influence over the entire economy and play pivotal roles in shaping its structure. They utilized input-output tables to apply measures that account not only for the patterns of ties but also for their value and actor centralization (García-Muñiz et al., 2008).

The statistics computed by García-Muñiz et al. (2008) encompass three key aspects. Firstly, the total effects, which gauge the relative total impact of one sector on the rest of the economy. Secondly, the immediate effects, which determine the immediacy in the network of the total effects. Thirdly, the mediative effects, a measure demonstrating the role of a specific sector in diffusing the total effects generated by other actors within the economy, acting as a crossroad in the network. Based on these three measures, García-Muñiz et al. (2008) constructed the influence index, which accounts for the structural characteristics where the weight of the sectors plays a central role. It aims to estimate the tendency of economic sectors towards sectorial influences.

This methodological framework was applied to both European and Spanish economic networks (García-Muñiz et al., 2008). For example, the total effects reveal that the construction sector, metal products, and non-metallic mineral products are pivotal to the Spanish economy. Meanwhile, within the European economy, sectors such as transport equipment, office data and processing machines, electrical goods, and agricultural and industrial machinery assume central roles. Furthermore, the influence index indicates that sectors oriented towards final demand exhibit a low level of influence, both in the Spanish and European contexts.

Input-output networks are often characterized by high density (DePaolis et al., 2022), given that nodes represent aggregated economic entities, such as firms. This results in nodes typically having numerous connections, including self-connections or recursive ties. DePaolis et al. (2022) demonstrate the significance of applying centrality measures specifically tailored for dense networks, with a particular example in the context of the United States. These measures provide valuable insights into the potential diffusion of economic shocks. For instance, they offer insights into the speed and direction of shock propagation.

Similarly, Alatriste Contreras and Fagiolo (2014) delved into the propagation of economic shocks, investigating how they amplify throughout the input-output network, conceptualized as a weighted graph with self-loops. Their study concentrated on developed economies, where they applied diffusion models to networks and calibrated them using input-output data. Additionally, they estimated Kleinberg's authority and hub centralities to identify key economic sectors.

Their findings underscore the importance of both the nature of the shock and the size of the country (Alatriste Contreras & Fagiolo, 2014). Shocks that affect final demand without altering production, along with the technological relationships between sectors, generally have a significant yet uniform impact on the economy. In contrast, when shocks also modify the magnitudes of input-output interdependencies across sectors, the economy tends to experience predominantly large but more varied avalanche sizes. Furthermore, large countries are more vulnerable to significant economic shocks. Concerning economic sectors, size alone does matter, but it is not the sole determining factor. The network position and the embeddedness in the complexity of input-output interconnections are also crucial considerations.

In order to model statistical input-output networks, García-Muñiz (2013) proposed a model to evaluate the topological characteristics of the network. The author compared the imports and the domestic Spanish economy for 1995 and 2009 using data from the World Input-Output Database (WIOD). By applying a p_1 model, García-Muñiz (2013) included network density, reciprocity, indegree, and outdegree centralities in the modeling process. The model demonstrated good performance in reproducing the network's structural patterns. The indegree model term showed influence on the domestic and imported relations. Meanwhile, the outdegree model term, representing the demand side of the economy, proved to be more effective in modeling the domestic network (García-Muñiz, 2013).

By employing a different application of network tools, Foerster and Choi (2017) investigated the United States' input-output network, utilizing network density as a measure of interconnectedness studied over the period from 1947 to 2015. They observed significant changes in the central sectors of the United States economy over time. In 1947, the central industries were primarily associated with transportation, primary metals, food and beverage, and farms. However, by 2015, the central industries had shifted to professional and scientific services, finance and insurance, administrative services, and transportation. Interestingly, wholesale trade and transportation and warehousing remained among the top five industries in the United States even after 68 years.

Weidong et al. (2022) delve into the relationship between input-output economic networks and the energy and mineral industries within the realm of physical economics. Their proposed framework involves identifying embodied energy, minerals, and other products, implicitly embedded within the input-output network relations. Employing a different strategy, Duan (2012) adopts a dynamic approach to model the evolution of national economies using input-output networks. They utilize a quantitative model to elucidate the dynamics among price, output quantity, and the input-output network. Through this analysis, they successfully explain synchronization during periods of rapid economic growth.

In Latin America, previous research has demonstrated the utility of analyzing Input-Output tables. Durán Lima and Banacloche (2022) emphasizes the significance of Input-Output tables in economic analysis as a foundation for policymaking. Moreover, they have contributed to a better understanding of intra-regional trade in services in South America (Banacloche, 2017), and productive specialization has been studied in the context of regional integration, also for the case of South America (Brondino et al., 2023). In Costa Rica, the input-output table has also been utilized to examine participation in global value chains (GVCs) through the analysis of import and export flows, in conjunction with bilateral trade balances (Bullón et al., 2014). Additionally, the classification of economic activities based on their concentration of employment and economic value has been investigated in Costa Rica employing the input-output table (Programa Estado de la Nación, 2017, Chapter 3). However, the application of input-output network approache to study economic interactions has not been widely utilized in Latin America.

Recently, Ramírez-Álvarez et al. (2024) conducted an analysis of the Ecuadorian input-output network, focusing on identifying the most influential industries in Ecuador. The authors applied four weighted centrality statistics—degree, closeness, betweenness, and alpha centrality. Additionally, they conducted cluster analysis based on k-means. Ramírez-Álvarez et al. (2024) found that primarily supply-driven activities such as retail trade, transportation, and professional activities are central in the network.

Márquez (2018) examined the influence of industrial exports from six Latin American countries—Mexico, Brazil, Chile, Argentina, Costa Rica, and Colombia. The author utilized the input-output matrix and network theory for this purpose. The study aimed to determine whether spillover effects from industrial exports in each country increase and diversify as the country's trade with the United States grows. Márquez (2018) suggests that spillover and feedback within an economic sector are higher when the sector is more integrated into the productive structure, thereby possessing greater capacity to influence others.

To achieve this objective, Márquez (2018) employed both weighted and non-weighted network centrality measures. The results indicated that spillovers of industrial exports are concentrated around inter-industrial networks of natural resource-based products and service activities. Furthermore, spillovers of trade in Argentina, Brazil, Chile, and Colombia are associated with basic metals, which have benefited from export activities. Meanwhile, in Costa Rica, spillovers are related to fabricated metal products, and in Mexico, to chemicals, computers, and electronic and optical equipment.

Although their analysis extended beyond Latin American countries, Soyyiğit and Çırpıcı (2017) examined the input-output networks of nine selected countries: China, Germany, Indonesia, India, Mexico, Russia, the USA, and Turkey. They employed Kleinberg's hub and authority centrality measures. Soyyiğit and Çırpıcı (2017) discovered that hub centralities indicate a decline in dependence on agriculture as the development level of economies increases. In highly industrialized countries such as the United States, Germany, and Japan, the scientific and technical activities sector, along with the financial sector, play crucial roles as suppliers in the economy. Regarding authority centrality, the sales sector is central in more developed countries, whereas in less developed countries, the food, construction, and services sectors assume central roles.

In addition to the input-output network approach, other researchers have explored alternative measures of economic complexity. Zaccaria et al. (2016) reviewed the measurement of economic competitiveness developed by Tacchella et al. (2012) and applied it to the case of the Netherlands. Their findings showed that developed countries tend to have diversified exports, whereas less developed countries typically export products of lower complexity.

In the context of trade relations, longitudinal studies using network approaches have also been conducted. Zaccaria et al. (2014) and Hidalgo et al. (2007) have made significant contributions in this area. Notably, Hidalgo et al. (2007) conducted an economic analysis that examined the concept of product space, revealing a core-periphery pattern in the trade network. Industrialized countries primarily represented by machinery, metal products, and chemicals occupy the core, while textiles, forest products, and animal-agricultural products dominate the periphery. Latin

American countries, engaging in activities such as trade, mining, agriculture, and garment production, are mostly situated on the periphery (Hidalgo & Hausmann, 2009).

Given the potential influence of network analysis on a country's economic decisions, the results presented in this study offer valuable tools for Costa Rica's decision-makers. This study represents a pioneering effort in exploring the interrelated and complex network of Costa Rica's domestic economy. The main objective is to identify the best positioned actors in the network by analyzing network centralities and positions. Initially, we identify the network structure, for this, we estimate central actors, and subsequently identify them within network subgroups. This analysis enables us to determine the actors that are best placed based on their network centralities and access to other network groups.

In summary, the primary overall objective of this study is to offer valuable insights into the structural characteristics of Costa Rica's economic network. Through the utilization of the Input-Output Matrix and network analysis methods, a comprehensive understanding of the interdependencies among economic actors can be achieved. The outcomes of this analysis hold significant potential in guiding policy-making processes and assisting decision-makers in the formulation of strategies aimed at promoting sustainable economic development.

II. METHODOLOGY

The methodology employed in this study centers around the analysis of Costa Rica's economic interactions using the Input-Output Matrix (I-O Matrix). Introduced by Leontief (1936, 1937), the I-O Matrix is a powerful tool for examining economic interrelations. It captures the relationships between industries or economic actors involved in the buying or selling of products. In this context, an economic actor is defined as a product within the I-O Matrix. To construct the matrix, enterprises and industries are classified based on their characteristics and economic activities. Consequently, the I-O Matrix can be seen as an adjacency matrix, portraying the interconnections of product purchases and sales within the economy. As recommended by Blöchl et al. (2011) and García-Muñiz et al. (2008), input-output networks must be studied as a weighted graph, where the transaction economic values give the weight of the linkages.

The focus of this study is specifically on the intermediate demand of domestic production. Consequently, it encompasses the purchasing and selling dynamics generated from national sources, excluding imports from the analysis. This constitutes 73.6% of the total intermediate demand, 47.4% of the final demand sourced solely domestically, and 41.3% of the final demand including imports, prior to considering taxes and subsidies. The official version of the 2014 I-O Matrix, developed by the Costa Rican Central Bank (BCCR) (Central Bank of Costa Rica, 2014), serves as the basis for this research.

The resulting system of relations forms a network of economic transactions, representing the interconnectedness of Costa Rica's economy. The adjacency matrix obtained has dimensions of 259 x 259 after removing isolated actors, and the weight of the relations represents the transaction value between economic actors. Here, "isolated actors" refers to activity codes that are absent in the country and therefore have no relationships, i.e. actors with no linkages. The resulting network is of a directed type, comprising 259 active nodes and 17,307 edges (relations), with an average of 133.64 relations per node. Each node represents an aggregation level of an economic sector, thus signifying an economic actor within the network.

Data processing was conducted using the R statistical framework (R Core Team, 2023). Specifically, the igraph package (Csardi & Nepusz, 2006) facilitated the estimation of network parameters. For network visualization, the Gephi (Bastian et al., 2009) software was utilized, employing the ForceAtlas2 (Jacomy et al., 2014) layout algorithm. Additionally, the adoption of the

Barnes-Hut algorithm within Gephi enhanced the representation of large and dense networks. We also estimated the statistic betweenness centrality using random walk for weighted graphs in R (2023) using the library xtranat (DePaolis et al., 2022; DePaolis, 2023).

It is important to note any potential limitations associated with this methodology. These may include constraints related to the Input-Output Matrix framework, data availability, or assumptions made during the analysis. Acknowledging these limitations is crucial for maintaining a comprehensive understanding of the research approach. To overcome the limitations of working with very dense networks, we estimated three centrality measures using random walk algorithms to calculate the statistics, as recommended by DePaolis et al. (2022).

In summary, this study applies the Input-Output Matrix and network analysis methods to explore the interconnections and dynamics of Costa Rica's domestic economic network. By leveraging the power of the matrix and employing suitable analytical tools, a deeper comprehension of the economic actors and their interdependencies is achieved. These insights bear relevance for policy-making and decision-making processes in Costa Rica.

To accomplish the study's objective, we utilized several network techniques. Network centrality analysis assisted in identifying individually important actors, while network subgroups played a crucial role in reconstructing the network structure and positioning individual actors within it.

Network centrality

A centrality analysis of the network enables the identification of the most significant economic actors in terms of their roles as sellers, buyers, and bridge builders. Traditional network statistics such as indegree, outdegree, and betweenness centrality (Freeman, 1977) are not suitable for studying input-output networks, as these networks tend to be dense and highly connected (Blöchl et al., 2011; DePaolis et al., 2022).

Counting Betweenness centrality

For weighted and densely connected networks, betweenness centrality based on random walks has been proven to be effective in identifying central actors (Blöchl et al., 2011; DePaolis et al., 2022). Thus, in this study, we implemented betweenness centrality using random walks for weighted graphs to identify economic actors with the most central role in connecting or bridging other actors, as adapted by DePaolis et al. (2022) from Blöchl et al. (2011). In this case, the probability of being central depends on the weight, number, and position of the existing linkages of the actor. According to DePaolis et al. (2022), it is also essential to include self-loops, as economic activities are aggregated; otherwise, many transactions will be overlooked. Therefore, we applied the counting betweenness refined by DePaolis et al. (2022), and applied using the R library xtranat (DePaolis et al., 2022; DePaolis, 2023).

In summary, random walk betweenness centrality is based on the concept of how much each node contributes as an intermediate node in the random paths generated between all pairs of nodes in the graph. According to DePaolis et al. (2022), this statistic shows the involvement of economic actors as they connect and intermediate others. Counting betweenness generalizes the random walk betweenness centrality initially developed by Newman (2005) by including self-loops.

The counting betweenness centrality for the case of the weighted graph for node i , b_i, has the following representation:

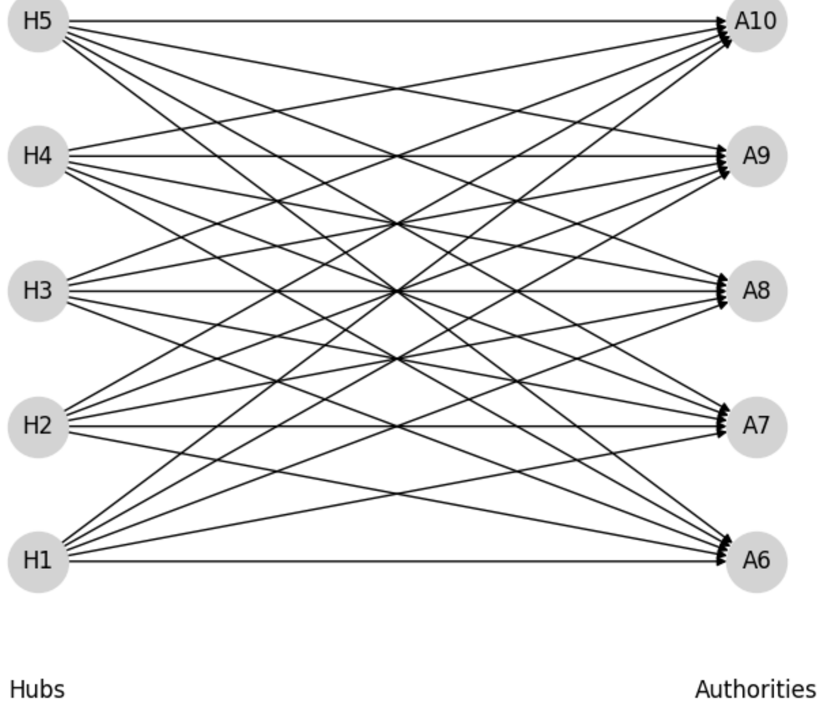
$b_i = \sum_{s=1} \sum_{t \neq s} \frac{N^{st}(i)}{n(n-2)}$, where $N^{st}(i)$ is the number of times the random walker passes through when moving from s to t.

Degree centralities

To estimate the degree centrality in the weighted network three main statistics were explored. First the node strength or weighted vertex degree, this was applied according to the notion developed by Barrat et al. (2004). The idea of estimating this type of measurement is to underscore hierarchies where weighted relations shape the structure of the network. The estimation is based on summing the edge weights of the adjacent edges of a specific node. The strength of the economic actor can be represented as follows (Barrat et al., 2004): $S_i = \sum_{j=1}^{N} a_{ij} w_{ij}$ .Where, the strength of the node, S_i ,is the sum of the relations between node i and any other actor j, considering the weight of this relation, w_{ij}.

We also estimated two additional network statistics for degree centrality of weighted graphs. The hub score and the authority score developed by Kleinberg (1999). The authority score represents how valuable the economic actor is as he demands inputs from many other actors in the economy. Meanwhile, the hub score shows how crucial an economic actor is by providing inputs to many other actors, playing a key role in propagating economic activity. For instance, an agricultural sector with high hub scores might supply essential raw materials to various manufacturing actors. This metrics are defined as the main eigenvector of the adjacency matrix and its transpose ($\mathbf{AA^T}$), this metrics are calculated using the random surfer model, where relations with larger weights influence the probability of being selected by the surfer (Csardi & Nepusz, 2006). A representation of the hubs and authorities is presented in Figure 1.

Figure 1
Representation of Kleinberg's hub and authority roles



Source: self-elaborated based on Kleinberg (1999).

Network subgroups

To identify potential subgroups within the networks, we leverage the advantages of this network analysis tool, which enables the identification of central individual actors within more complex structures and the delineation of their corresponding roles. For this analysis, we employed the Walktrap method (Ponds & Latapy, 2006), which utilizes a random walk approach to reconstruct an actor's neighborhood. This algorithm is particularly well-suited for efficiently estimating network structure in large and dense networks (Ponds & Latapy, 2006).

Specifically, the Walktrap algorithm iteratively merges actors into communities based on the linkages among their members. The objective is to minimize the distance between members within each community while maximizing the distance between communities (Ponds & Latapy, 2006). By applying this process, we establish the final network subgroups, with each actor assigned to a specific subgroup at the conclusion of the iterative process.

One important consideration is that the likelihood of an actor belonging to a specific subgroup is influenced by the size of its neighborhood, which refers to the number of connections it has. Consequently, actors with a significant number of connections may be better captured by longer random walks, while actors with fewer ties may be better captured by shorter walks (Ponds & Latapy, 2006). Furthermore, in dense networks, smaller walks tend to provide a better representation than in sparse networks (Ponds & Latapy, 2006).

For reconstructing the network subgroups using the Walktrap method, we employed shorter random walks based on the identified communities. Specifically, the algorithm was configured to utilize four-step walks, effectively capturing the distinct smaller network subgroups that form an interconnected economic structure.

III. RESULTS

Identifying network subgroups

The aim of the network group analysis is to identify nodes that form subgroups, thereby characterizing the structure and role of the subgroups in the formation of the network. The results show that the economic actors are connected in small and middle-sized groups. At this point, the algorithm has successfully reconstructed these economic subgroups. Figure 2 depicts the network representation of Costa Rica's economy. Here, the colors of the nodes represent the Walktrap subgroups. Dense areas consists of clusters of actors who share links and are attracted to groups of actors with whom they share relations. These areas are connected to other zones of the network by means of economic transactions. The areas on the periphery show that ties that bring actors closer are weaker and less dense than at the center of the graph. The center of the economy gathers many of the economic actors, this region is the most dynamic from an economic perspective, with densely interconnected actors.

As already mentioned, Figure 2 shows the formation of several clusters. The term "cluster" here specifically refers to a bunch of actors close to each other in Figure 2. This term is different from that of the network subgroup identified using the Walktrap method. A cluster is constructed by the network layout algorithm ForceAtlas2 implemented in the software Gephi. This algorithm locates nodes closer if their ties attract each of them to a specific cluster. In other words, an actor is in a cluster if its relations to actors in this cluster are more than actors in another cluster. It is like a gravity attraction in terms of space nearness.

On the other side, the network subgroups depend on the distribution and number of linkages that the actors have to other subgroups. Thus, this depends on the distribution of actor's degree between the subgroups built (Ponds & Latapy, 2006). Hence, a cluster in Figure 2 may have actors from different network subgroups, which may include different economic activities within a cluster.

To summarize, there are clusters composed of actors with different subgroup colors. For example, in Figure 2, a red-colored actor may be surrounded by blue-colored actors. While they are neighbors, the red-colored actors are primarily connected to other red-colored networks identified by the method. This is also evident in Figure 2, where some groups are not tightly connected, resulting in a lack of cohesion. Consequently, nodes with diverse memberships are dispersed. Nevertheless, it is still possible to identify clusters in the network consisting mostly of actors from the same subgroup color. In Figure 2, the red nodes are in the largest subgroup, gathering 44% of the actors. Green nodes represent 22% of the actors, blue nodes gather 20% of the actors, light grey nodes account for 3%, and orange nodes represent 2% of the actors. As mentioned earlier, the membership of the actors in network subgroups was assigned by 4-step random walks. More specifically, three larger network subgroups were identified, as well as three medium-sized ones, as well as several small groups and some actors behaving almost individually. The main subgroups identified are as follows:

- Group A (red-colored actors in Figure 2): The largest subgroup, gathering 44% of the actors. It includes different areas of the economy, ranging from textiles not including garments (NP066E) to lubricating oils and greases (NP076D), electronic components and boards, computers and peripheral equipment (NP096E), commerce-related services (NP126E), and postal and courier services (NP138D).

- Group B (blue-colored actors in Figure 2): It gathers 20% of the actors. It includes actors related to meal products (NP061D and NP065D), meal supply services (NP140D). In addition, it includes raw materials, mostly related to agriculture and foods, and actors closely related to these activities, for example, beans (NP001D), other fruits, nuts, and other oleaginous fruits (NP026D), tubers (NP012E) and oranges (NP023E), and other plastic products (NP087D).

- Group C (green-colored actors in Figure 2): This subgroup gathers 22% of the actors. It includes a variety of goods and services, the dominant actors are those related to transport and associated activities, e.g., motor vehicles, bodies, trailers, and semi-trailers (NP107D), highways and railways (NP123D), and automotive machinery and equipment rental services (NP163E).

In addition, smaller subgroups include:

- Group D (light grey-colored actors, 3% of the actors): This subgroup includes fishery products and industries derived from these, e.g., fishing products (NP037E), preserved fish, shellfish, and mollusks (NP047E), and prepared food for animals (NP062E).

- Group E (orange-colored actors, 2% of the actors): This subgroup includes animal production, its subproducts, and related industries, e.g., cattle (NP028D) and meat and edible offal of pigs (NP045D).

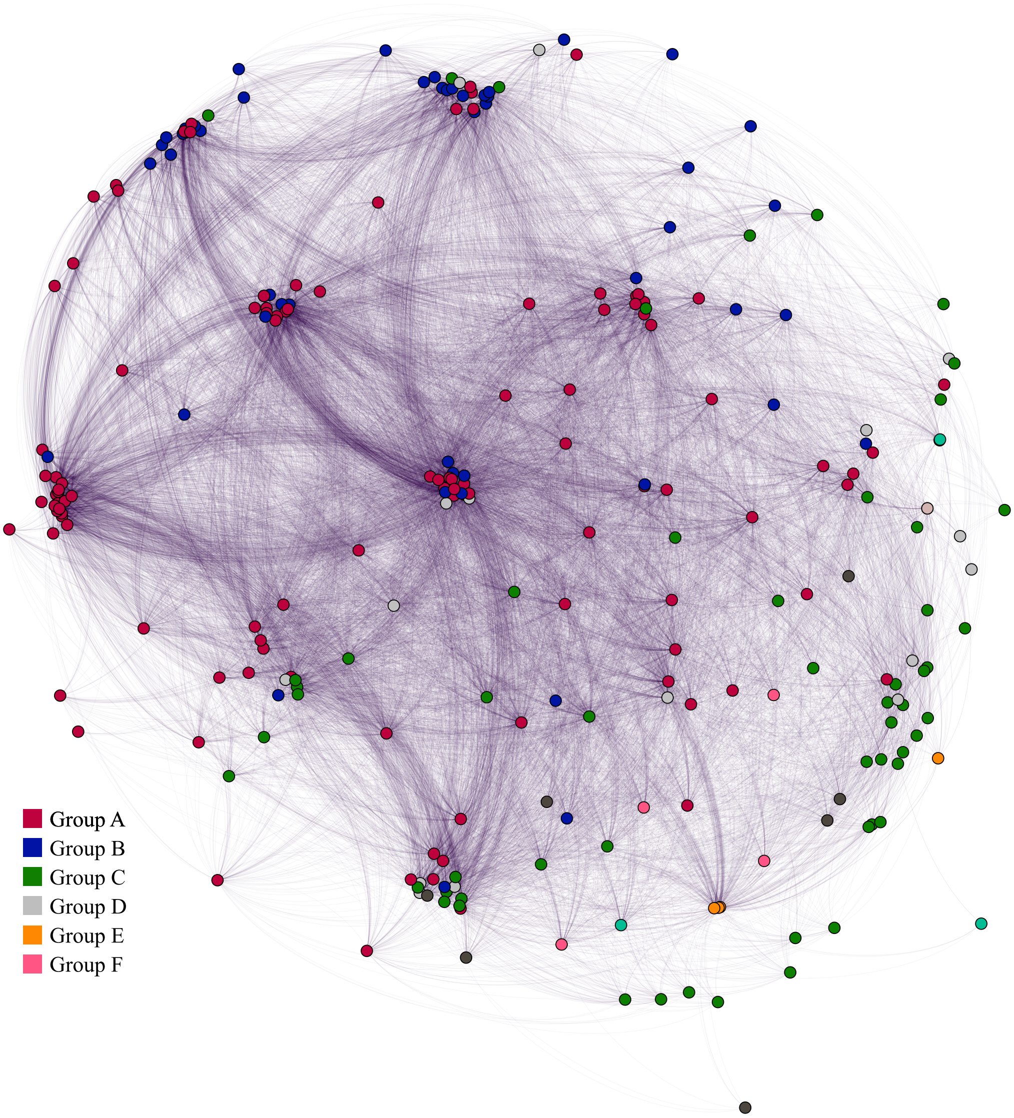
- Group F (pink-colored actors, 1.5% of the actors): This subgroup includes poultry-related products and subproducts, e.g., chicken (NP030D) and meat and edible poultry offal (NP043D).

Micro subgroups:

- Group G (other colors, 7.5% of the actors): comprises various very small subgroups characterized by high diversity and a small number of members, with most groups consisting of two to three actors.

Importantly, by recognizing the clusters formed and understanding the composition of the network subgroups, we gain valuable insights into the diverse sectors of the economy and their interrelationships within the network.

Figure 2
Costa Rica's Economic Network



Source: self-elaborated with data of the Central Bank of Costa Rica (2014).

To summarize, the economic actors in Costa Rica form small and mid-sized clusters dispersed throughout the network, with actor memberships corresponding to the previously described subgroups. These findings prompt an important question about the level of centrality of economic actors. The objective is to identify the actors that are best positioned in the network. This information is relevant for the following reason:

-Best-positioned actors: Identifying these actors is crucial for public policy, as it allows for targeted support to specific subgroups that are performing well economically. Understanding their connections can facilitate the more effective diffusion of economic benefits throughout the network.

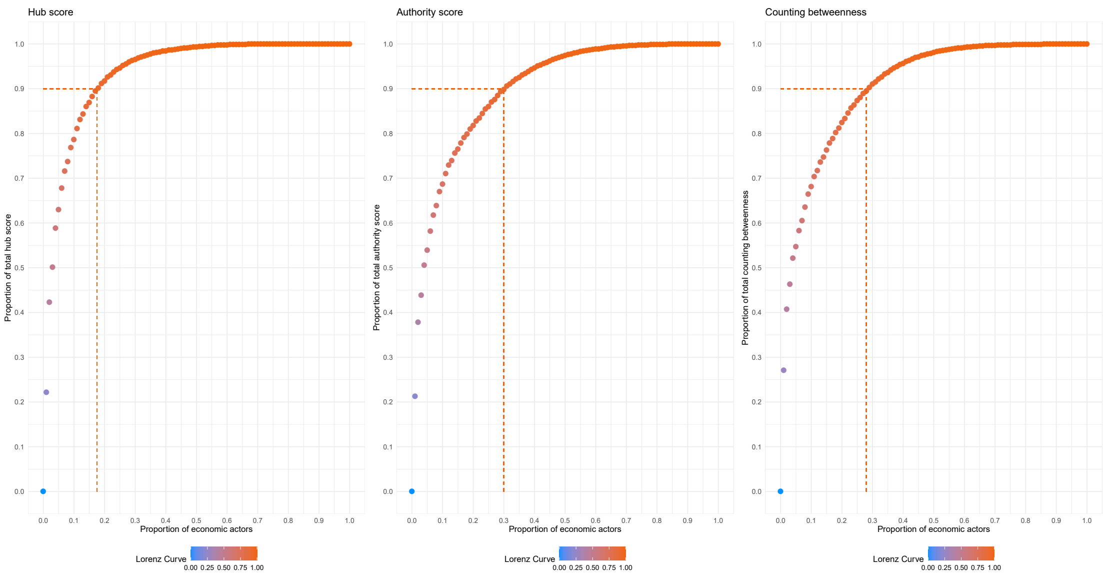
In the following section, we will proceed to identify the actors that fall into these best placed positions within the network.

Network centrality

Here, we present the results of the hub score, authority score, and counting betweenness centrality. Regarding the hub score, the results showed a 79% correlation with the strength statistic, with the top five values corresponding to the same economic actors. Consequently, we opted not to present the strength centrality results, as the main behavioral trends are already captured by the hub score.

The findings indicate a high concentration of centrality within the network, with only a few actors holding significant influence. This observation is supported by the Lorenz Concentration Curve (Figure 3), commonly used in economics to illustrate the concentration of GDP, income, or other resources among specific actors. The distribution of the three statistics reveals a hierarchical structure within the network. For the hub score, 90% of the total score is concentrated in just 17.5% of the economic actors. Similarly, the authority score indicates that 90% of the total score resides with 30% of the actors. Additionally, the counting betweenness highlights that 28% of the actors account for 90% of the total counting betweenness. The hub score exhibits slightly higher concentration among a select few actors compared to the authority score, the betweenness centrality is also highly concentrated.

Figure 3
Lorenz Concentration Curve of Network Centralities of the Costa Rican Economy



Source: self-elaborated with data of the Central Bank of Costa Rica (2014).

The distribution of hub and authority score centralities indicate a hierarchical order within the network, where only a small number of actors occupy central positions in transactions involving the exchange of goods and services. These influential actors establish valuable economic relationships with many others, underscoring their pivotal role in the network. Similarly, the distribution of counting betweenness centrality reveals a high skewed pattern, suggesting that only a select few economic actors serve as crucial bridges within the economic structure. Consequently, this highlights the significance of identifying key intermediaries in understanding the global interconnectedness of the network. It's important to note that high betweenness centrality does not necessarily imply high hub or authority scoring.

Summarizing, these findings illuminate the structural characteristics of the network, revealing a skewed distribution of weighted degree centralities and counting betweenness among specific actors. Understanding these distribution patterns contributes to a more comprehensive analysis of the network's structure, facilitating informed decision-making regarding economic dynamics, resilience, and potential interventions. To delve deeper into the interrelationships among economic actors, we proceed to identify the main economic actors based on the three measures used so far.

Hub score

Remembering that the hub score refers to the outdegree of influential actors towards authoritative actors. Thus, the hub score may be seen as an important node in the network with many relations that also hold significant economic value. It can be seen as an influential seller delivering goods and services. For the case of Costa Rica's economy, these actors are shown in Table 1:

Table 1
The five highest hub score actors

Actor	Description	Value	Subgroup
NP125D	Specialized construction services	1	C
NP154D	Non-residential property rental services and other real estate services	0.72	A
NP126D	Commerce related services	0.60	A
NP160D	Advertising services, provision of advertising space, and market research	0.52	A
NP148D	Indirectly measured financial intermediation services (IMFIS)	0.45	A

Source: self-elaborated with data of the Central Bank of Costa Rica (2014).

The first ranked economic activity is the specialized construction related services, which denotes the growing constructing activity that the country has had. Followed by non-residential property rental services and other real estate services, commerce related services, advertising services and financial intermediation. Specialized construction services is the only economic actor that belongs to the network subgroup C, the others are from subgroup A.

Authority score

The authority score reveals the principal economic actors that receive goods and services from important economic actors. It can be seen as a measure of popularity, it represents an actor that is closely connected with highly valuable actors in the economy. These actors are shown in Table 2:

Table 2
The five highest authority score actors

Actor	Description	Value	Subgroup
NP126D	Commerce related services	1	A
NP122D	Non-residential buildings	0.73	C
NP121D	Residential buildings	0.50	C
NP124D	Construction of public service projects and other civil engineering works	0.50	C
NP153D	Rental housing services	0.37	C

Source: self-elaborated with data of the Central Bank of Costa Rica (2014).

In the case of the authority score, there is a complete correspondence with high hub scores. Residential and non-residential construction, along with housing services, are expected to be economically related to construction and real estate activities. Commerce-related services appear on both sides, as hubs and as authorities, indicating potential self-related economic ties. This last actor belongs to the network subgroup A, and the other four activities to the subgroup C.

Counting betweenness

The counting betweenness statistic identifies actors that function as connectors, thereby linking diverse economic actors and facilitating significant economic flow, as they participate in various processes and transactions across different sectors. Counting betweenness yields valuable insights into potential access to economic transactions. A high counting betweenness implies ties that augment economic exchange between subgroups, while a low counting betweenness suggests that agents do not act as intermediaries; hence, it is not pertinent as an overall connector to the economy. These actors are enumerated in Table 3.

Table 3
The five highest counting betweenness actors

Actor	Description	Value	Subgroup
NP175D	Services for human health care and social assistance	14.15	A
NP140D	Food and beverage supply service	6.35	B
NP126D	Commerce related services	5.37	A
NP061D	Meals, prepared dishes, and other food products	2.53	B
NP174D	Educational services	2.29	A

Source: self-elaborated with data of the Central Bank of Costa Rica (2014).

The identified actors encompass a variety of economic activities, including health services, food supply services, commercial services, and educational services. Thus, four out of five activities pertain to services, while one relates to meal products. The predominant network subgroup is A, comprising three members, followed by subgroup B with two members.

As already mentioned, these actors function as connectors between various economic sectors, engaging in the exchange of goods and services. The mentioned actors are pivotal players deeply integrated into the economic dynamics of the country, possessing numerous connections and strong economic ties. Additionally, they have access to multiple subgroups within the network. Three of these actors are affiliated with subgroup A, which constitutes 44% of the total number of actors.

IV. DISCUSSION

The present study aims to describe and estimate relevant network structural characteristics of Costa Rica's economy in order to identify weaknesses and strengths that need to be addressed for the improvement of productive chains and the promotion of economic growth. This study is one of the first of its kind in the country, focusing on analyzing Costa Rica's domestic demand depicted in the I-O Matrix.

In a broader context, according to the Atlas of Economic Complexity, Costa Rica ranks 46th out of 133 countries in terms of complexity, based on the Economic Complexity Index (Hausmann et al., 2011) (updated online to 2017). This suggests that Costa Rica's economic performance is more complex than its income level alone would suggest. The diversification of knowledge has led to a broader array of goods and services at the export level. To further diversify its economy, Costa Rica should adopt a parsimonious industrial policy approach, addressing bottlenecks to facilitate the transition towards new related products (Hidalgo et al., 2007). Thus, a general appreciation of Costa Rica's economic context already indicates areas for improvement.

From the input-output table analysis, Costa Rica also faces significant challenges. For example, the main economic sectors such as education, health, medical supply products, and commercial services have significant weight in production; however, they have a low capacity to generate employment (Programa Estado de la Nación, 2021, Chapter 3). As observed, these influential industries are well-known for their capacity or lack of capacity to create economic value and employment, but their role within the input-output network at the domestic level remains unclear. For this reason, our input-output network approach aims to make a significant contribution as we identify the roles of key actors, which information can be used for possible policy challenges that need to be addressed.

We have observed a highly skewed distribution in the Lorenz curves for hub score, authority score, and counting betweenness. Consequently, the concentration of centrality in a few actors may have both positive and negative implications. Policymakers can leverage the central role of these actors to positively influence various aspects of the economy by reaching multiple actors simultaneously. Furthermore, high counting betweenness actors plays a crucial role in connecting economic sectors that may not have direct contact otherwise, thereby fostering cohesion within the economic structure. However, the dependency on a small number of actors to maintain global cohesiveness also poses risks. These actors wield significant economic influence, suggesting a level of vulnerability in the Costa Rican economic framework. The vulnerability here is understood in the context of Alatriste Contreras and Fagiolo's (2014) study on the potential propagation of economic shocks throughout input-output networks. They emphasize that the position and embeddedness of an economic sector matter when it comes to the propagation of effects.

In general, our research reveals that commercially related services, construction services, and health and educational services play critical roles and exhibit strategic connections with actors across multiple network subgroups. Thus, improving these services and activities would enhance the network position and economic performance of numerous actors. More specifically, the only economic actor that ranked in the top five for all three network metrics used was commerce-related services (NP1206D). This highlights the crucial role of commercial activities in the Costa Rican economy at all levels: as providers and consumers of other goods and services, and as intermediaries between other economic sectors.

When observing only the role of providers, the hub score places specialized construction services (NP125D) in first place, followed by non-residential property rental services and other real estate services (NP154D). Thus, the central and strong position of these actors as suppliers clearly indicates the development of the infrastructure and real estate market in the country. In the third and fourth places, we find commercial services (NP126D) and provision of advertising space, and market research (NP160D), respectively. This highlights that commercial activities and the promotion of these products and services play a central role in the economy. Financial intermediation (NP148D) also ranks fifth, revealing the significant role of the financial market services in Costa Rica's economy.

Considering these three types of actors, we can conclude that there are three major types of activities positioned as providers in the economy: first, construction and real estate services; second, commercial and advertising services; and third, financial services. Thus, there exists an interesting diversity of economic sectors playing this central role, with a clear dominance of services. Importantly, the network subgroup that dominates this ranking is subgroup A, with only construction services (NP125D) belonging to subgroup C. This highlights the significant role played by subgroup A in the network. Subgroup A consists of central actors that occupy favorable positions and provide essential services demanded by actors across various economic sectors. It includes not only actors with higher hub centralities but also one engaged highly in bridging activities, such as commercial services (NP126D).

In the case of the authority score's top five values, commercial services (NP126D) ranks first, followed by non-residential buildings (NP122D), residential buildings (NP121D), construction of public service projects and other civil engineering works (NP124D), and rental housing services (NP153D). Unlike the hub score, the authority centrality is clearly focused on buildings, construction, and housing, goods and services associated with urban and construction development. Meanwhile, commercial services (NP126D) appear to be widespread in the economy and strongly demanded by other economic actors. The network subgroups were mostly dominated by subgroup C, with only commercial services belonging to subgroup A.

Therefore, high authority scores imply that the actors are important recipients of various sources of goods and services, while high hub scores define them as key suppliers to many other value-added activities. In both cases, these actors are involved in high-value economic transactions with many others, resulting in a significant supply and exchange of goods and services, which implies substantial investments. Hence, policymakers must consider these activities if they aim to stimulate the economy or mitigate potential shocks.

Soyyiğit and Çırpıcı (2017) examined the input-output networks of nine selected countries, including Mexico, and found that less developed and industrialized countries commonly have food, construction, and services sectors assuming central roles in the authority score. Considering Costa Rica as a non-industrialized country, we observe a high degree of coincidence with the results of the authority score, which place construction services and commercial services centrally in the network. Therefore, the generalization made by Soyyiğit and Çırpıcı (2017) seems to match the case of Costa Rica.

On the other hand, the scientific and technical activities sector, along with the financial sector, play crucial roles as suppliers in more developed economies, with high hub scores (Soyyiğit & Çırpıcı, 2017). At the same time, the dependency on raw agricultural goods is reduced. Our findings show that Costa Rica's high hub score centrality resides more in construction services, commercial services, and financial services. In this case, there is one coincidence with the more developed economies, since financial services are a key economic player in the network. This, together with the absence of agricultural raw goods in the top five ranking, may suggest a potential evolution in the hub role players of Costa Rica's economy. However, further research is needed to confirm this possible evolution.

By identifying the top five economic actors based on counting betweenness centrality, we observe three groups of actors. Firstly, there are the services related to health and education. Here, we find the highest value attributed to services for human health care and social assistance (NP175D, subgroup A), and the fifth highest value attributed to educational services (NP174D, subgroup A). Both actors belong to network subgroup A.

The second group consists of actors associated with meals and food goods and services. Two actors are identified: food and beverage supply services (NP140D, subgroup B) and meals, prepared dishes, and other food products (NP061D, subgroup B). Both of these actors belong to network subgroup B. Finally, commercial services (NP126D, subgroup A) rank third and could be considered a distinct type as they encompass various commercial services associated with retail and wholesale, such as those related to garments, groceries, hardware stores, and vehicles, among others.

These actors play a bridging role in the network, connecting numerous sectors and different network subgroups. They facilitate the flow of economic activities and influence the overall network dynamics. This is possible because these actors are strategically located and engaged in significant exchanges of high-value goods and services. As a result, they not only mediate interactions but also handle important transaction values. Therefore, prioritizing them in policies and investments can enhance the economic performance of the Costa Rican economy. For example, they can play a key role in interventions aimed at increasing resilience in the case of economic shocks, thereby reducing vulnerability. This is feasible since high counting betweenness centrality can indicate how quickly and in which direction the flow could be affected (DePaolis et al., 2022).

Following the above idea, another relevant interpretation of high counting betweenness is that these actors have mediative effects, as explained by García-Muñiz et al. (2008), and modeled and applied by DePaolis et al. (2022). These effects refer to the high involvement of the identified actors as instruments to transmit total effects, as they play a crossroad role in the economic network. The total effects are seen as the overall impact of one sector on the rest of the economy (García-Muñiz et al., 2008). Therefore, health and education services, commercial services, and food and meal goods and services can translate the impact of one specific economic sector to other parts and subgroups of the network. The importance of the policy design exercise lies in considering that it could diffuse either a positive or negative impact.

The importance of these products is further supported by the Programa Estado de la Nación (2022, Chapter 3). For example, prepared food and meals have an aggregated product value exceeding 47%. Consequently, the quality of the identified services for other actors is key to success. Conversely, a decline in quality, reduced resilience, and a diminished capacity to adapt to new challenges can limit growth, as may be the case in the quality of health and education services.

A study conducted by Márquez (2018) identified key sectors for several Latin American countries, including Costa Rica. By employing a network approach and input-output tables, the author identified the following key economic sectors for Costa Rica: food products, beverages, and tobacco; pulp-paper products, printing, and publishing; coke, refined petroleum products, and nuclear fuel; and basic metals. Interestingly, only food-related products coincide with our results. Márquez (2018) primarily found goods as central economic actors; however, our findings indicate that Costa Rica's main key economic players are services. The differences may stem from Márquez (2018) estimating non-weighted centrality statistics and combining them with spillover analysis. Nevertheless, an analysis solely based on non-valued networks can lead to the loss of important information for economic networks (García-Muñiz et al., 2008), thus potentially misleading the comparison of findings.

Additionally, Ramírez-Álvarez et al. (2024), analyzing the Ecuadorian input-output network by using weighted centrality measures, found that activities such as retail trade, transportation, and professional activities are central in the network. In this case, Costa Rica coincides with the Ecuadorian economy in that commercial activities (including retail commerce) are central actors in the economy, as indicated by all three network centrality statistics. Further research comparing the input-output networks of Latin American countries using the same methodological approaches can shed light on the similarities among key actors and their network roles. This may help to strengthen the idea of pursuing regional economic policies.

The counting betweenness centrality also highlights the difference between a small, developing economy and a large, industrialized one. For example, the United States has professional, scientific, and technical services; insurance carriers and related real estate; administration and support services; and utilities bridging their economy (DePauli et al., 2022). Meanwhile, our findings show that Costa Rica has health and educational services, commercial services, and food and meal services in these connecting positions. Hence, both economies facilitate network brokerage through different types of services.

From a different network application not utilizing counting betweenness but rather applying network density, Foerster and Choi (2017) identified similar actors for the United States. They found that in 2015, the central industries were professional and scientific services, finance and insurance, administrative services, wholesale trade, and transportation and warehousing. Both studies by DePauli et al. (2022) and Foerster and Choi (2017) coincide that in the United States, professional, scientific, and technical services; finance and insurance; and administration and support services play a central role in the economy. Although the explanation of the differences between the United States economy and Costa Rica's economy lies beyond our scope, it is important to note that network centrality measures are able to reflect the differences in economic key role players.

We compared our counting betweenness centrality results with the mediative effects observed by García-Muñiz et al. (2008) in their study of the Spanish and European input-output networks. García-Muñiz et al. (2008) reveal that in Spain, five primary sectors serve as pivotal points in the network: 1. building and construction, 2. auxiliary transport services, 3. metal products except machinery, 4. lodging and catering services, and 5. non-metal mineral products. García-Muñiz et al. (2008) noted that Spain exhibits a traditional economic structure, characterized by a significant presence of the metallurgical industry, which is reflected in the mediative measure.

Comparing these findings to Costa Rica's higher counting betweenness centrality, it appears that the two economies share few commonalities, except for lodging and catering services in Spain, and food and beverage supply services, meals and prepared dishes, and other food products in Costa Rica. While these activities are not identical, they highlight the importance of food-related services in connecting various sectors in the network. In Spain, lodging and catering services may be linked to tourism, a prominent industry in the country. Similarly, tourism is a significant sector in Costa Rica, demanding for food and meal services.

In Europe, the top five mediative sectors are: 1. transport equipment, 2. building and construction, 3. auxiliary transport services, 4. marine and air transport services, and 5. agricultural and industrial machinery. García-Muñiz et al. (2008) suggested that Europe holds a stronger position in the high technological segment if compared to Spain. For instance, agriculture and industrial machinery are central players in Europe. Nonetheless, both the Spanish and European economies share certain high mediative sectors, such as auxiliary transport services and building and construction. The prominence of transport-related sectors in Europe may reflect the extensive movement of goods and people within the European Union. In contrast, the high counting betweenness centrality sectors in Costa Rica differ from those observed in Europe.

Summarizing, the findings reveal that subgroup A comprises the most central actors of the Costa Rican economy, including four of the highest hub scores, the highest authority score, and three of the highest counting betweenness actors in the network. Thus, this subgroup is particularly significant as it encompasses strategically located actors with strong influence within the network. Additionally, the key actors are primarily oriented towards services, such as commercial services, construction services, financial services, food and meal services, and health and educational services. Recognizing these actors is the first stage for policymakers if they aim to have a significant and valuable systemic impact on the economy.

As a final remark, it is worth mentioning that studying the input-output network yields important contributions. The inclusion of systemic complexity through the study of economic networks, as proposed by Schweitzer et al. (2009), can greatly contribute to the design of effective policies and strategies. By considering the interdependencies and interactions within the network, policymakers can better understand the dynamics and behaviors of the economic system as a whole, rather than focusing solely on individual actors or sectors.

This systemic approach helps to reduce conflicts between individual interests and the overall efficiency of the network. By recognizing the interconnected nature of economic activities, policies can be designed to promote collaboration and cooperation among actors, leading to improved efficiency and effectiveness in resource allocation, production, and trade. Therefore, a well-interconnected economic network is more robust and resilient to shocks and disturbances, as emphasized by Cerina et al. (2015), Carvalho (2014), and Schweitzer et al. (2009).

V. CONCLUSIONS

Based on our results, we have shown that Costa Rica's most central actors are primarily based in services, with commerce-related services ranking among the top five in all three network statistics applied. This provides solid evidence that commercial activities are the main driving force in the intermediate demand. This is evident as they serve as both important suppliers and consumers of goods and services. Furthermore, these activities act as a bridge within the economy and its different subgroups. Therefore, a major consideration for policymakers is that interventions and stimulation in commercial services will have broad and overall effects on the entire economy.

Apart from commercial services, other significant contributors include construction services and rental, and real estate services. These activities are intimately correlated with urban and residential growth trends. It's important to note that the aggregation level is national, so further detailed investigations are necessary to determine the regionalized and local implications of economic movements in these activities. This will allow local authorities to consider stimulating local economies and planning their territories accordingly.

The authority scores reflect the importance of economic activities such as residential and non-residential building construction and rental housing in Costa Rica's economy. This reinforces the idea that urban development and infrastructure play a central role in the economy by generating significant flows of goods and services. Moreover, essential services such as health and education strategically connect the network, as evidenced by their high counting betweenness. Promoting these services can have a significant positive impact on the economy, not only from a mere monetary perspective but also because they serve as crossroads along the network, diffusing their benefits. Additionally, enhancing the quality of these types of services may increase resilience in the economy as they create capacities and benefits that stay within the network and can be spread to other economic sectors.

Another important actors bridging the economic flow of the network are food and meal products and services. These activities demand raw agricultural products and sell to other sectors such as commerce. Costa Rica's central actors have shown that raw products are not strategic players from a network point of view. Whereas central actors have shown to be diverse, referring to different types of services. Therefore, a future dynamic-historic network analysis can show the process of transformations of the network economy and the transition that key actors have had. Thus, further research is needed to understand the dynamic processes involved in the input-output network.

Finally, more research is needed to emphasize the regional context in which Costa Rica operates, including comparisons with other Latin American countries using the same methodological approach.

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