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Bipartite Supplier–Healthcare Network Analysis for Detecting Communities and Structural Dependencies in Chile's Public Procurement of Medical Equipment

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***Abstract*—Open government data have significantly increased the availability of information about public procurement processes; however, despite the growing use of network analysis to study economic and institutional interactions, structural dependency between suppliers and public health institutions has rarely been operationalized as a measurable property of procurement networks, a limitation particularly relevant in medical equipment markets, where supplier concentration may affect the resilience and continuity of healthcare services. To address this gap, this study models Chile's public medical equipment procurement system as a weighted bipartite network constructed from awarded purchase orders published on the national e-procurement platform (*www.mercadopublico.cl*) between January 2022 and April 2025, connecting 204 public healthcare institutions with 249 suppliers through 1,420 procurement transactions. Community detection based on modularity optimization reveals eleven well-defined structural groups characterized by dense internal connectivity and relatively sparse inter-group links, indicating a clear structural organization of the market in which high-value procurement relationships are strongly concentrated in specific technological segments, notably in imaging and surgical equipment, where a small number of multinational suppliers account for a disproportionate share of the total transaction volume, while other communities display more diversified procurement patterns involving multiple suppliers and mid-range purchase values. Supplier dependency is formally quantified using the Herfindahl–Hirschman Index (HHI) computed per community, revealing that the imaging-dominated community exhibits high concentration ($HHI = 0.340$), whereas surgical communities show low to moderate levels ($HHI \leq 0.200$). These findings provide a structural characterization of Chile's medical equipment procurement ecosystem and demonstrate that network-based approaches, combined with explicit concentration metrics, can support the identification of supplier dependency risks in public healthcare markets, contributing to the development of analytical tools for evidence-based procurement planning and risk monitoring in health technology management.**

***Index Terms*—Public Procurement Networks, Bipartite Networks, Supplier Dependency, Community Detection, Medical Equipment Markets**

I. Introduction

Chile's official electronic public procurement platform, *www.mercadopublico.cl*, serves as the main transactional infrastructure through which government institutions publish tenders and execute purchase orders exceeding USD 10 billion annually, equivalent to approximately 3.5% of the national gross domestic product, and involving more than 120,000 registered suppliers across the country [1]. Within this system, the health sector occupies a particularly strategic position due to the technological complexity and economic magnitude associated with medical equipment procurement. In practice, decisions regarding the acquisition of diagnostic and therapeutic technologies directly affect the operational capacity of healthcare institutions and, consequently, the continuity and quality of patient care.

At the same time, the growing availability of open government data has created new opportunities for studying public procurement processes. The Transparency Law (No. 20,285) requires that procurement transactions be publicly accessible, allowing administrative records to be transformed into analytical evidence capable of supporting planning and decision-making in areas such as clinical engineering and health technology management [1], [2]. This is especially relevant in Chile, where the public health insurance system (FONASA) provides coverage to more than 75% of the population. As a result, procurement decisions made within the public sector have a direct impact on the technological infrastructure that supports a large share of healthcare services nationwide [3].

From an analytical perspective, the procurement platform can be understood as a socio-technical system composed of multiple interacting actors. Public healthcare institutions, medical technology suppliers, equipment categories, financial transactions, and regulatory procedures coexist within the same procurement environment. Over time, repeated interactions between buyers and suppliers generate relational structures that shape the organization of the market. These structures may reveal patterns of collaboration, specialization, and dependency between specific institutions and suppliers.

Network science offers a suitable framework for analyzing these types of complex interactions. In graph-theoretical terms, actors can be represented as nodes and their relationships as edges [4]. When applied to procurement systems, this

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representation enables the construction of buyer–supplier networks in which healthcare institutions and suppliers are connected through procurement transactions. Once modeled as a network, these interactions can be analyzed using community detection techniques that identify groups of actors with stronger internal connectivity relative to the rest of the system [5]. Such communities may reflect technological specialization, recurrent procurement partnerships, or structural segments of the market that are difficult to detect through conventional descriptive statistics.

Modularity-based methods have proven particularly effective for identifying these structures. Algorithms such as the Newman–Girvan modularity approach [6] and the fast-unfolding method proposed by Blondel *et al.* [7] allow large networks to be partitioned into communities with dense internal connections and relatively sparse external links. Previous studies have applied these techniques to analyze the Chilean public procurement ecosystem [8] as well as interaction structures in other complex systems, including social and technological networks [9]. These works demonstrate that network-based approaches can reveal structural patterns that remain hidden within large transactional datasets.

Despite these advances, an important limitation remains. While network analysis is often used to visualize procurement relationships or identify clusters of actors, supplier dependency is rarely addressed as a measurable structural property of procurement networks. This issue is particularly relevant in healthcare technology markets, where excessive reliance on a small number of suppliers may create risks related to pricing power, technological lock-in, and supply chain disruptions. Understanding whether such dependency patterns exist, and how they are distributed across technological segments, therefore remains an open research question.

In this context, the present study models Chile's medical equipment procurement market as a weighted bipartite network constructed from open procurement data. Rather than merely describing procurement transactions, the study interprets the public medical equipment market as a structured relational system in which concentration, specialization, and supplier dependency can be examined through both network topology and formal concentration metrics.

More specifically, this study pursues three objectives: (1) to construct a curated dataset of medical equipment procurement transactions derived from open government records; (2) to represent buyer–supplier relationships as a weighted bipartite network that captures both relational connectivity and economic magnitude; and (3) to identify structural communities and formally quantify supplier dependency within each community using modularity-based clustering and concentration indices.

The remainder of the paper is organized as follows. Section II describes the methodological approach used to construct and analyze the procurement network. Section III presents the empirical results, including the global network structure, community identification, and supplier dependency metrics.

II. Materials and Methods

A. Chilean Context and Data Source

This study analyzes awarded purchase orders related to medical equipment procurement recorded between January 2022 and April 2025 on the Chilean national electronic procurement platform (*www.mercadopublico.cl*). The platform constitutes the official transactional infrastructure for public procurement processes in Chile and provides open access to procurement records through the national open data portal [10], [11].

Each procurement record includes key attributes describing the transaction, such as supplier and buyer identifiers, product category, awarded amount, procurement date, and purchasing region. Because the dataset originates from publicly available administrative records, no personally identifiable information was processed. Consequently, all analyses comply with the open-data framework established under Chilean transparency regulations [2].

To ensure analytical consistency, only procurement processes that resulted in awarded purchase orders were retained. Canceled, voided, or incomplete procurement procedures were excluded. This filtering step ensured that the resulting dataset represented effective economic interactions between healthcare institutions and suppliers.

B. Data Processing and Structuring

The initial dataset contained approximately 280,000 procurement records. A multi-stage data processing workflow was implemented to construct a dataset suitable for network analysis.

First, variables directly associated with procurement interactions were selected. These included `SupplierName`, `PublicAgency`, `GenericProductName`, `CategoryN3`, `PurchaseRegion`, `Cost`, `Month`, `Year`, and `EquipmentType`. These attributes capture both the identity of the actors involved and the technological and economic characteristics of each transaction.

Second, a semantic filtering procedure was applied to isolate procurement records corresponding specifically to medical equipment. The filtering criteria followed the World Health Organization definition of medical equipment as devices requiring calibration, maintenance, repair, user training, and decommissioning for diagnostic, therapeutic, monitoring, or rehabilitation purposes [12]. Based on this definition, 46 clinically relevant procurement categories were retained.

Third, these categories were grouped into eight broader technological classes representing major functional domains within hospital infrastructure, including Imaging, Life Support and Ventilation, Surgical and Endoscopic Equipment, Monitoring and Diagnostics, Sterilization and Infection Control, and Clinical Furniture. Aggregating categories in this way allowed more interpretable comparisons between technological segments within the procurement network.

Awarded procurement amounts were stratified into four economic bands: 10–25 million CLP, 25–50 million CLP, 50–100 million CLP, and more than 1,000 million CLP. This categorization facilitated the identification of structural patterns associated with high-value technological investments.

To improve data quality, supplier and institution names were standardized to correct variations in spelling and formatting. Duplicate entries were removed, and records with missing supplier, buyer, or awarded amount information were excluded. After completing these procedures, the curated dataset consisted of **1,420 procurement transactions**.

Two relational tables were then constructed for network modeling: a node table containing suppliers and healthcare institutions, and an edge table representing procurement transactions between them. Each edge corresponds to a purchase order linking a buyer to a supplier, while the associated edge weight represents the monetary value of the awarded contract.

C. Graph Theory and Network Construction

Buyer–supplier relationships were modeled as a weighted bipartite graph $G = (U, V, E, w)$, where the node set U represents suppliers and the node set V represents healthcare institutions. Edges E connect nodes exclusively across the two sets and correspond to procurement transactions between institutions and suppliers.

Each edge e_{ij} was assigned a weight w_{ij} corresponding to the awarded monetary value of the purchase order. The weighted adjacency matrix $A = [a_{ij}]$ was defined such that $a_{ij} = w_{ij}$ when a transaction exists between institution v_i and supplier u_j, and $a_{ij} = 0$ otherwise. This representation captures both the existence of procurement relationships and their economic magnitude.

Within this framework, structural metrics were examined to characterize the procurement ecosystem. In particular, node degree reflects the number of procurement relationships associated with an actor, while weighted degree represents the cumulative value of transactions connected to that actor. These indicators allow the identification of suppliers and institutions occupying structurally central positions within the network.

Global connectivity indicators were also examined to assess whether procurement interactions exhibit a core–periphery organization in which a subset of actors concentrates a significant share of transactional activity.

D. Community Detection and Modularity

To identify structural clusters within the procurement ecosystem, community detection techniques were applied to the bipartite network [5]. Communities correspond to groups of nodes that exhibit stronger internal connectivity relative to the rest of the network. In procurement systems, these clusters may reflect technological specialization, regional procurement patterns, or recurrent buyer–supplier relationships.

The quality of a community partition was evaluated using the modularity metric Q, originally introduced by Newman and Girvan [6]:

$$Q = \frac{1}{2m} \sum_{i,j} \left[A_{ij} - \frac{k_i k_j}{2m} \right] \delta(c_i, c_j), \tag{1}$$

where A_{ij} represents the weighted edge between nodes i and j, k_i and k_j correspond to node degrees, m denotes the total number of edges in the network, and $\delta(c_i, c_j)$ equals 1 when nodes belong to the same community.

Higher values of Q indicate stronger separation between communities, meaning that edges are more densely concentrated within groups than between them. Values of $Q > 0.3$ are generally interpreted as evidence of meaningful modular structure [5].

Community detection was implemented using the modularity optimization algorithm available in *Gephi*, based on the fast-unfolding method proposed by Blondel *et al.* [7]. The algorithm iteratively groups nodes in order to maximize modularity while maintaining computational efficiency for large networks.

To evaluate the stability of the detected communities, the algorithm was executed under multiple random initializations and small variations in the resolution parameter. Across these runs, the resulting partitions showed consistent modularity values and community counts, indicating stable structural patterns within the procurement network.

E. Supplier Dependency Metrics

To move beyond structural description and formally quantify supplier dependency within each community, this study applies the Herfindahl–Hirschman Index (HHI) [14] and node centrality measures to each detected community.

The HHI for community c is defined as:

$$\text{HHI}_c = \sum_{i=1}^{n_c} s_i^2, \tag{2}$$

where s_i denotes the share of supplier i in the total awarded value of community c, and n_c is the number of suppliers within that community. Values of HHI < 0.15 indicate a competitive market structure, values between 0.15 and 0.25 indicate moderate concentration, and values exceeding 0.25 indicate high concentration and elevated dependency risk [14].

In addition, the weighted degree s_i^w and betweenness centrality $C_B(i)$ of each dominant supplier were computed. Weighted degree captures the total economic volume transacted by a supplier, while betweenness centrality measures the extent to which a supplier lies on the shortest paths between other actors in the network, reflecting its structural intermediation role. Together, these metrics provide a quantitative basis for assessing the degree of structural dependency associated with specific supplier–institution configurations.

F. Tools and Visualization

Network construction, analysis, and visualization were conducted using the open-source network analysis platform **Gephi**. The network was imported as a weighted bipartite graph with edge weights corresponding to the monetary value of awarded procurement transactions.

Several network metrics were examined to characterize the structure of the procurement ecosystem, including node degree, weighted degree, betweenness centrality, and modularity-based community assignments. For visualization purposes, the

ForceAtlas2 layout algorithm was applied. This force-directed layout positions strongly connected actors closer together while pushing sparsely connected nodes toward the periphery [13].

The resulting visualization facilitates the interpretation of community structure, highlights central actors in the procurement network, and supports the identification of structural patterns associated with specialization, concentration, and supplier dependency in Chile's medical equipment market.

III. Results

A. Profile of the Analyzed Dataset

The curated dataset comprised **1,420** awarded purchase orders involving **204** public healthcare institutions and **249** suppliers. Over the observation period, procurement demand was not evenly distributed across technological categories. Instead, transactions were strongly concentrated in *Surgical and Endoscopic Equipment* and *Imaging*, while the remaining categories appeared less frequently and in a more fragmented pattern.

This distribution indicates that public investment in medical technologies tends to prioritize a limited set of high-impact technological domains, whereas other equipment categories are acquired more sporadically and often through isolated procurement processes (Fig. 1). From an analytical perspective, this asymmetry suggests that the procurement ecosystem does not operate as a homogeneous market. Rather, it is composed of technological segments characterized by different levels of transactional intensity and potentially different supplier structures.

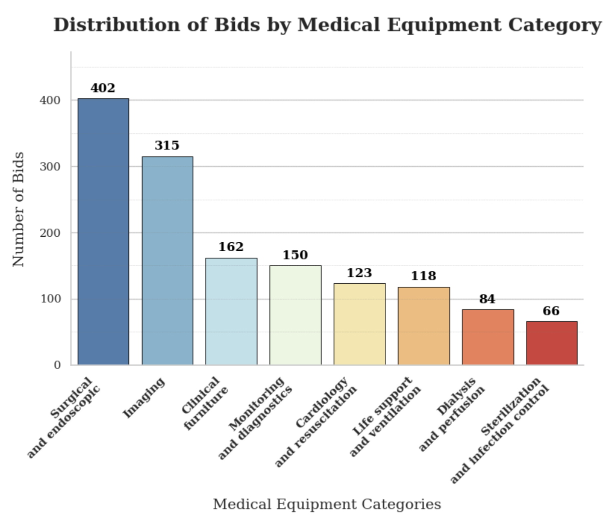

Fig. 1. Distribution of medical equipment procurement transactions by technological category. Surgical and endoscopic equipment and imaging dominate the observed procurement volume. Chile, Jan. 2022–Apr. 2025.

B. Global Network Structure and Communities

The resulting weighted bipartite network comprised **453 nodes** (249 suppliers and 204 healthcare institutions) connected through **1,420 procurement relationships**. The structural representation of this network reveals a topology characterized by a **dense central core** surrounded by several **peripheral relational structures**.

Community detection identified **11 communities** with a modularity value of $\mathbf{Q = 0.639}$, well above the 0.3 threshold considered indicative of strong modular organization [5]. This result confirms that procurement relationships are not randomly distributed across institutions and suppliers but instead form structured relational clusters shaped by recurring acquisition patterns.

To improve visual interpretability, nodes with weighted degree values below the network mean (**19.508**) were excluded from the visualization, highlighting the actors with the highest economic and relational connectivity (Fig. 2). Under this representation, the network exhibits clear clusters organized around specific supplier–institution configurations.

At a structural level, three concurrent phenomena become apparent. First, the existence of a dense core indicates that a relatively small subset of actors concentrates a disproportionate share of procurement activity. Second, the segmentation of the network into well-defined modules reflects technological and institutional specialization within the procurement ecosystem. Third, the variation in HHI values among communities confirms that supplier dependency is unevenly distributed across technological segments.

C. Communities with the Highest Participation in the Network

To facilitate interpretation while preserving representativeness, the analysis focused on the five largest communities (C1–C5), which together account for more than half of the nodes, connections, and awarded procurement value observed in the network. Table I summarizes the structural and dependency indicators for each of these communities.

Table I reveals that the procurement ecosystem is internally heterogeneous: some modules are organized around diversified supplier portfolios and medium-value transactions, whereas others are dominated by a limited number of highly central suppliers and technologically complex procurement segments.

1) Community 1: Community 1 exhibits a multi-actor procurement configuration centered on *Importadora y Distribuidora Arquimed Ltda.*, with *Sur Medical SpA* and *Hogg y Serrano* also playing visible roles (Fig. 3). On the institutional side, the community includes several regional health services such as *SS Los Ríos*, *SS O'Higgins*, *SS Atacama*, and *SS Coquimbo*.

The dominant technological category is *Surgical and Endoscopic Equipment*, followed by *Monitoring and Diagnostics*, *Clinical Furniture*, and *Cardiology and Resuscitation*. Most procurement transactions fall within the **25–50 million CLP** and **50–100 million CLP** ranges. The HHI value of 0.136 confirms a competitive supplier structure with no dominant actor concentrating a disproportionate share of the awarded value. The betweenness centrality of Hogg y Serrano ($C_B = 12{,}689$) indicates a strong intermediation role within this community, connecting multiple institutions and product categories.

2) Community 2: Community 2 is composed of suppliers including *Medtronic Chile*, *Comercial Medtronic Chile Ltda.*,

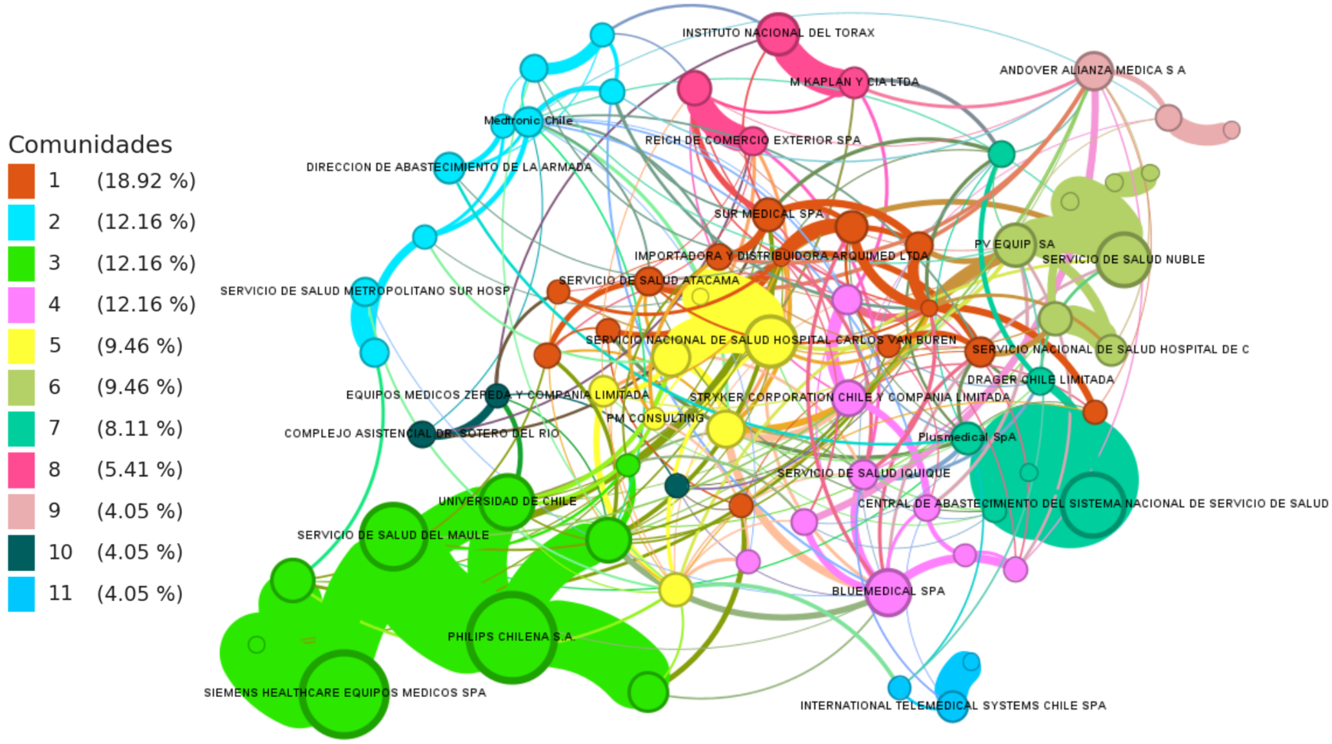

Fig. 2. Buyer–supplier network of Chile's public medical equipment procurement market. Edges represent procurement transactions weighted by awarded value. Nodes with weighted degree below the network mean were filtered to emphasize structurally central actors.

TABLE I
STRUCTURAL AND DEPENDENCY INDICATORS FOR THE FIVE LARGEST PROCUREMENT COMMUNITIES

Community	Nodes	Suppliers	Institutions	Trans.	Value (M CLP)	HHI	Concentration	Dominant Supplier
C1 (Surgical/Multi)	96	41	55	193	7,215	0.136	Low	Hogg y Serrano
C2 (Medtronic/Defense)	65	44	21	118	3,472	0.053	Low	Medtronic Chile
C4 (Bluemedical)	58	27	31	108	3,697	0.169	Moderate	Bluemedical SpA
C5 (GE Healthcare)	27	16	11	61	3,155	0.200	Moderate	GE Healthcare
C3 (Imaging)	30	20	10	57	9,865	0.340	**High**	Siemens Healthcare

Importadora y Exportadora Camir SpA, and *Alcon Laboratorios Chile Ltda.* These suppliers are connected to institutions such as the *Dirección de Abastecimiento de la Armada*, the *Fuerza Aérea de Chile Comando Logístico*, *Hospital Dr. Gustavo Fricke*, and the *Servicio de Salud Metropolitano Sur* (Fig. 4).

This community is notable because it connects civilian healthcare institutions with defense-sector procurement bodies, suggesting the existence of a transversal acquisition network rather than a purely hospital-centered procurement segment. The HHI of 0.053 is the lowest among the five communities, confirming a highly distributed supplier structure. Most transactions fall within the **10–25 million CLP** range.

3) Community 3: Community 3 represents the clearest case of structural concentration in the network. It is dominated by *Siemens Healthcare Equipos Médicos SpA* and *Philips Chilena S.A.*, both of which connect to high-complexity institutional buyers including *SS Maule*, *SS Magallanes*, *Hospital Base de Valdivia*, *SS Coquimbo*, *Universidad de Chile*, and the *Servicio de Salud Metropolitano Sur Oriente* (Fig. 5).

Within this community, *Imaging* is the dominant technological category, and several procurement transactions exceed **1,000 million CLP**. The HHI of 0.340 formally confirms high supplier concentration, exceeding the 0.25 threshold associated with elevated dependency risk [14]. The weighted degree of Siemens Healthcare ($s^w = 256.56$) is the highest among all dominant suppliers, reflecting its overwhelming transactional centrality within this market segment. This configuration is consistent with the technological characteristics of advanced medical imaging markets, where high entry barriers, complex equipment ecosystems, and specialized maintenance requirements reduce the number of viable suppliers.

4) Community 4: Community 4 is structured mainly around *Bluemedical SpA*, with *Stryker Corporation Chile y Cía. Ltda.*

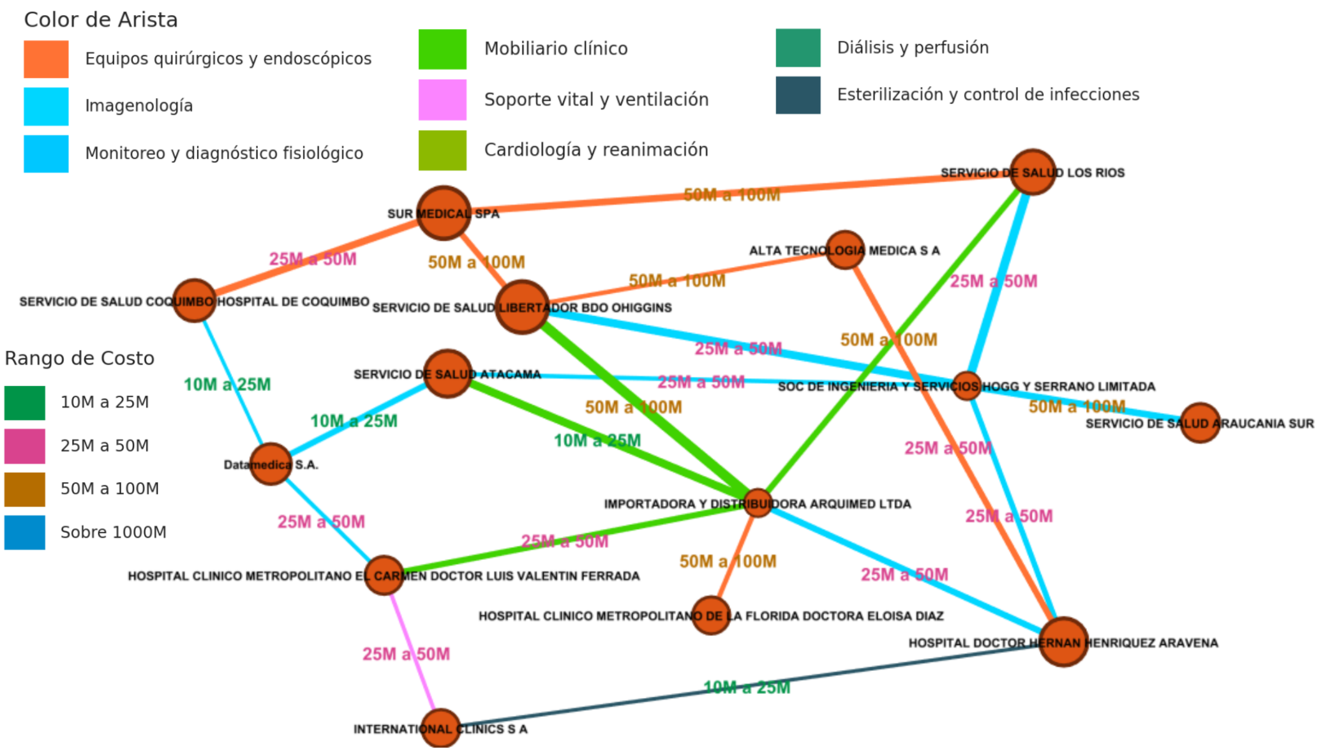

Fig. 3. Internal procurement relationships within Community 1, showing a multi-supplier structure centered on Arquimed and several regional health services.

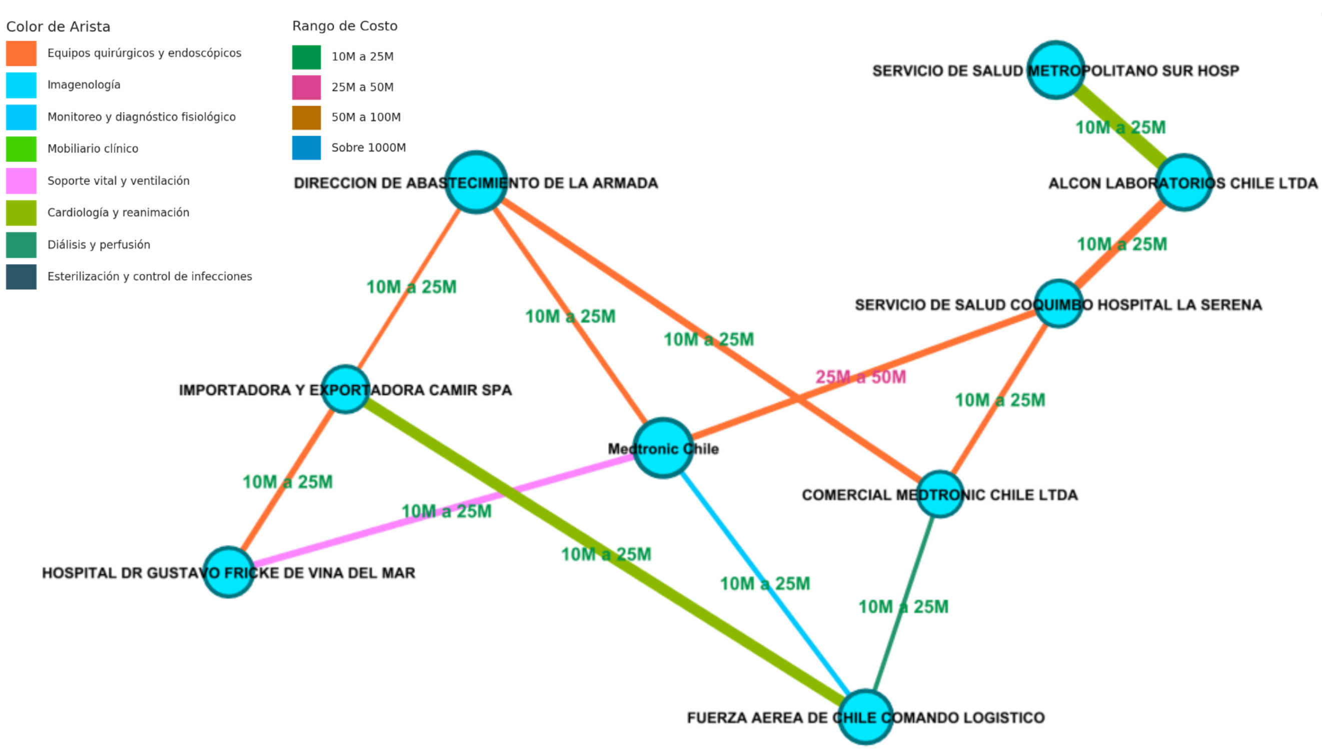

Fig. 4. Internal structure of Community 2, linking civilian healthcare institutions with defense-related procurement bodies.

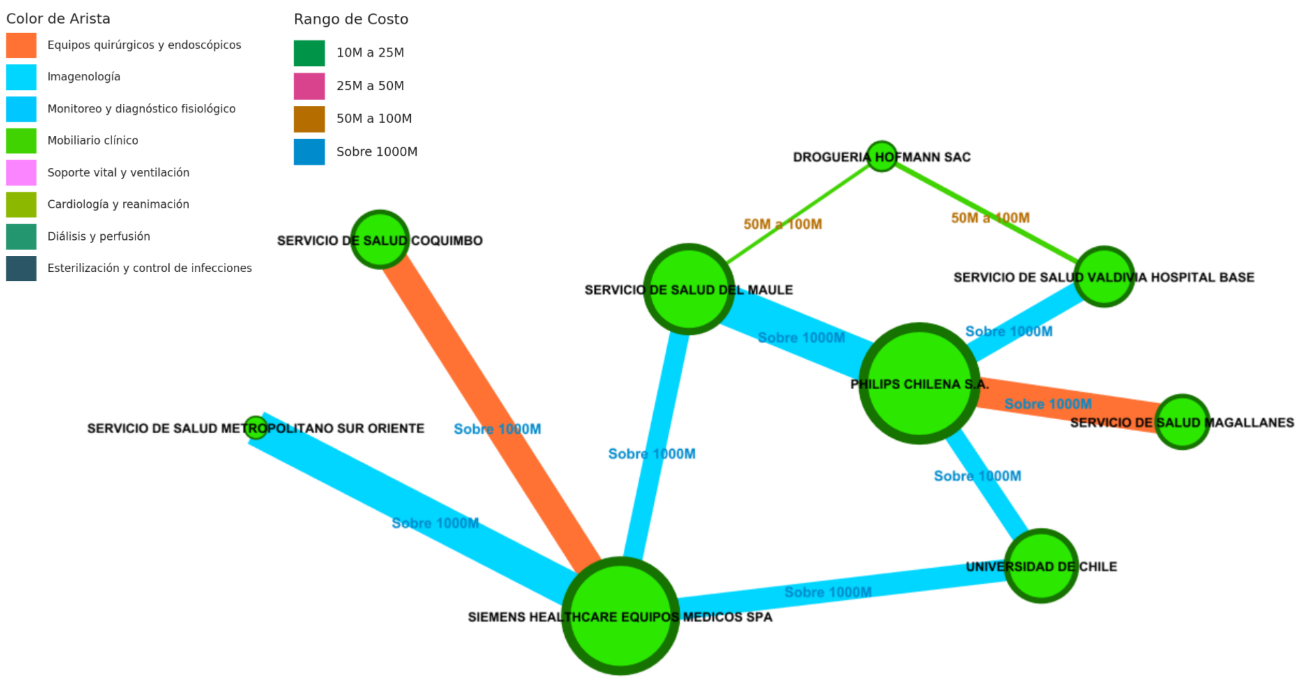

Fig. 5. Community 3 network structure showing strong concentration of high-value imaging procurement around Siemens Healthcare.

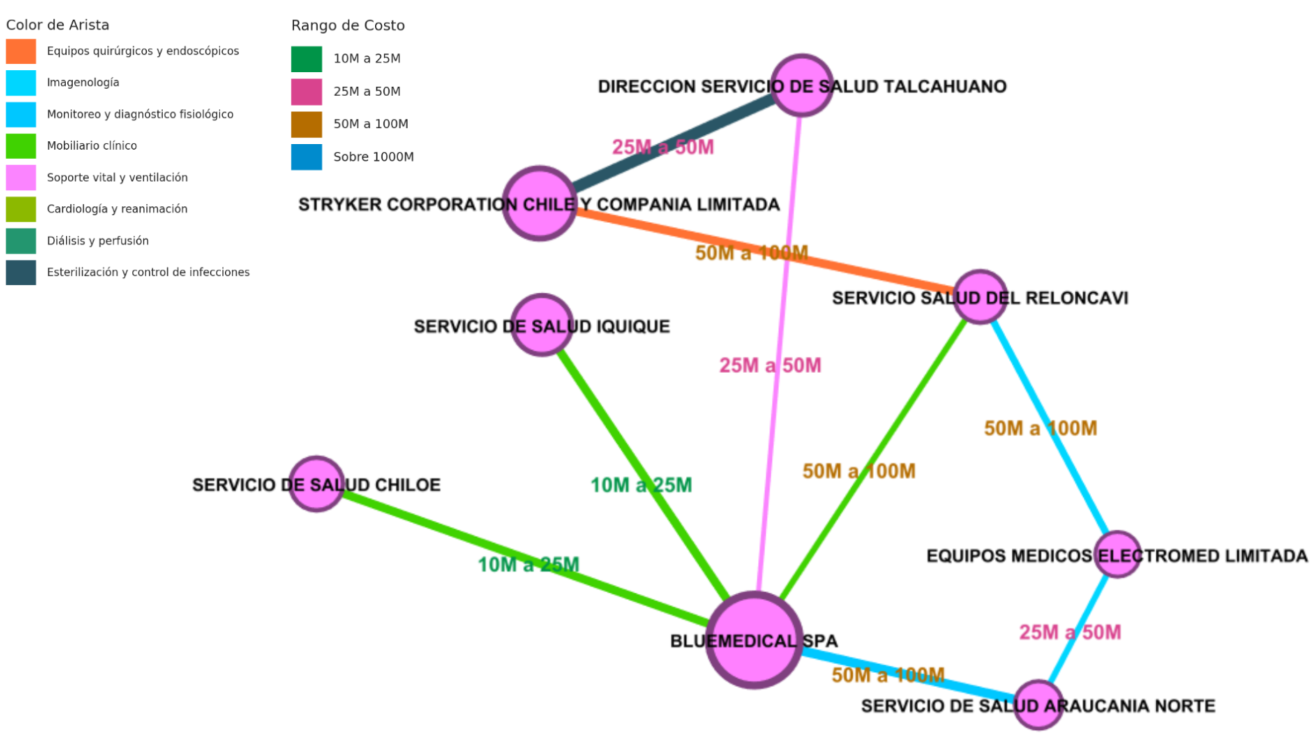

Fig. 6. Community 4 showing regional procurement patterns centered on Bluemedical and several southern healthcare institutions.

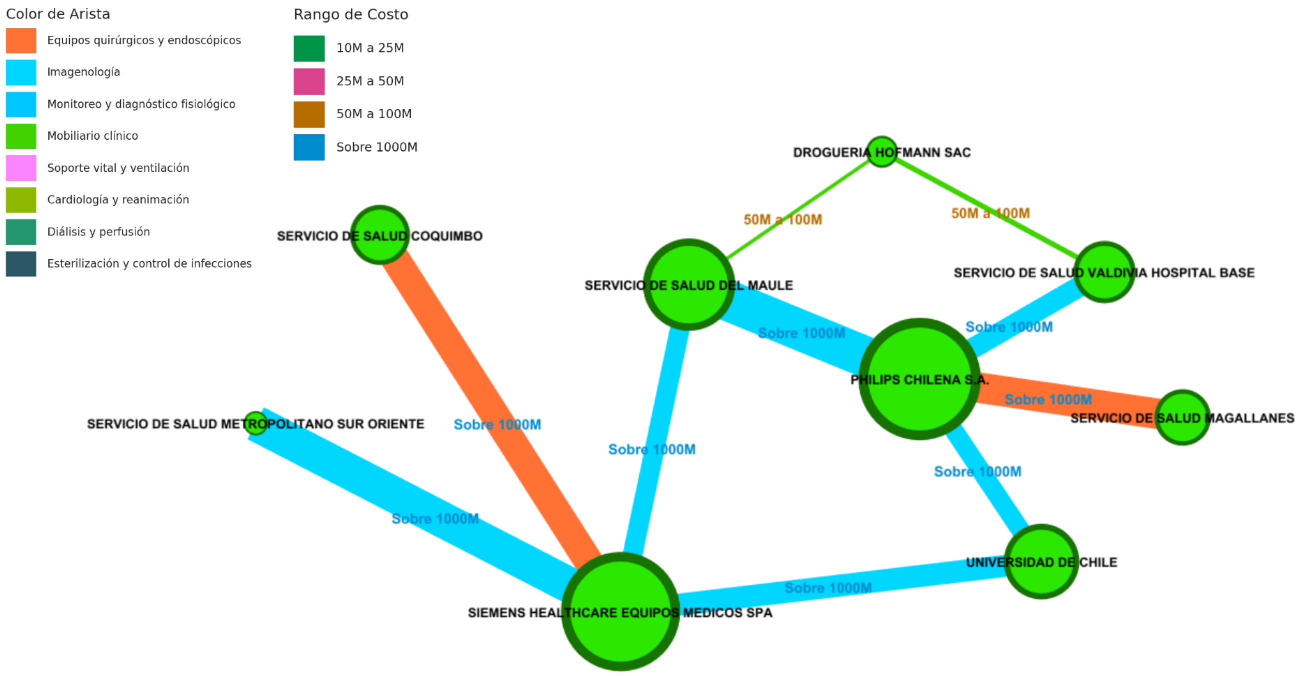

Fig. 7. Community 5 structure highlighting high-value procurement relationships between GE Healthcare and Hospital Carlos Van Buren.

and *Equipos Médicos Electromed Ltda.* also occupying relevant positions (Fig. 6). On the institutional side, the community includes actors such as *SS Chiloé*, *SS Iquique*, *SS Araucanía Norte*, *SS Reloncaví*, and the *Dirección Servicio de Salud Talcahuano*.

The dominant technological categories include *Life Support and Ventilation*, *Clinical Furniture*, and *Surgical and Endoscopic Equipment*. Procurement amounts typically range between **10 million CLP** and **100 million CLP**. The HHI of 0.169 indicates moderate concentration, and the high betweenness centrality of Bluemedical ($C_B = 10{,}351$) confirms its significant structural intermediation role across southern healthcare institutions.

5) Community 5: Community 5 connects suppliers such as *GE Healthcare International LLC Agencia en Chile*, *Megalabs Chile S.A.*, and *PM Consulting* with institutions including *Hospital Carlos Van Buren*, *SS Viña del Mar–Quillota*, and *SS Metropolitano Norte Hospital San José* (Fig. 7).

The technological composition includes *Life Support and Ventilation*, *Imaging*, and *Surgical and Endoscopic Equipment*, while procurement values range from **10 million CLP** to more than **1,000 million CLP**. The HHI of 0.200 indicates moderate concentration. A particularly notable structural feature is the zero betweenness centrality of GE Healthcare ($C_B = 0$), indicating that its relationship with Hospital Carlos Van Buren is a direct and exclusive bilateral tie that does not serve as a bridge toward other actors in the network, which reinforces the localized dependency pattern within this community.

IV. Discussion

The results indicate that Chile's public medical equipment procurement system operates as a structured relational ecosystem rather than a homogeneous transactional marketplace. The modularity value ($Q = 0.639$), substantially above the 0.3 threshold, confirms that procurement interactions are organized into specialized buyer–supplier configurations with meaningful internal cohesion [5].

The formal application of the HHI reveals that supplier dependency is not uniformly distributed across the network but varies substantially by technological segment. Communities C1 and C2 present HHI values of 0.136 and 0.053 respectively, indicating competitive structures in which procurement activity is distributed across multiple suppliers. Communities C4 and C5 fall in the moderate range (HHI = 0.169 and 0.200), suggesting emerging concentration that warrants monitoring. Community C3, with an HHI of 0.340, formally exceeds the high-concentration threshold [14], confirming that imaging procurement in Chile's public health system presents a measurable and structurally significant dependency risk concentrated around Siemens and Philips.

This finding aligns with the broader dynamics of health technology markets, where high entry barriers, equipment standardization, and long-term maintenance requirements reduce the number of viable suppliers. The combination of high HHI, elevated weighted degree ($s^w = 256.56$), and economically dominant transactions exceeding 1,000 million CLP positions Community C3 as the segment of highest structural vulnerability within the analyzed network.

The results also illustrate how procurement ecosystems can extend beyond traditional administrative boundaries. The presence of defense-related procurement bodies within Community C2 alongside civilian health services would remain difficult to identify through conventional descriptive procurement statistics alone, highlighting the analytical value of network-based approaches for comprehensive market surveillance.

Finally, the contrast between the betweenness centrality values of dominant suppliers reveals different roles within their respective communities. High betweenness values (e.g., Hogg y Serrano with $C_B = 12{,}689$) indicate suppliers that actively intermediate across multiple institutional buyers, while GE Healthcare's zero betweenness confirms a structurally isolated bilateral dependency. These distinctions have direct practical implications for procurement risk management and supplier diversification strategies.

V. Conclusion and Future Work

This study modeled Chile's public medical equipment procurement market as a weighted bipartite network derived from open government procurement data. The analysis identified **11 structural communities** ($Q = 0.639$), revealing that procurement interactions are organized into differentiated relational modules rather than a single homogeneous market structure.

The formal application of the Herfindahl–Hirschman Index per community provides the first quantitative assessment of supplier dependency in this procurement ecosystem. The imaging-dominated Community C3 presents an HHI of 0.340, confirming high concentration and elevated dependency risk, while surgical and mixed-supply communities exhibit low to moderate concentration levels. These results demonstrate that network analysis combined with concentration metrics can generate actionable structural evidence about specialization and dependency in healthcare technology markets.

The proposed framework illustrates how open procurement data can support more informed and resilient decision-making in public healthcare systems. Future work should apply randomized bipartite network null models to evaluate the statistical significance of detected communities, incorporate temporal analysis of community evolution over time, and extend the framework to other countries within the PAHO region to assess the replicability and generalizability of the proposed methodology.

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