

Paraguay's Business Innovation System: Structure, Challenges and Opportunities

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Abstract

This study analyzes Paraguay's business innovation system during the 2018-2020 period using a neo-Schumpeterian approach. The research applies social network analysis to innovation survey data, constructing bipartite networks with system actors and companies to examine linkages both at the systemic level and by specific innovation objectives.

The analyzed network presents low density (0.012) and intermediate modularity (0.203), indicating strategic selectivity in relationships with six distinct communities. Results reveal a hierarchical system dominated by commercial actors: Customers achieve perfect eigenvector centrality (1.0) while Universities and Laboratories remain peripheral (centralities 0.2387 and 0.2174). Sectoral analysis shows manufacturing dominance (65.58%) with specialization of the information and communications sector in knowledge-intensive activities (38.42% in R&D networks). Objective-specific networks exhibit significant variation, with R&D showing the highest connectivity (density 0.030) and financing the greatest fragmentation (modularity 0.554).

The findings reveal a pattern of "dominant commercial intermediation" in innovation systems of small emerging economies, where customer-supplier relationships substitute traditional institutional linkages as the primary mechanism for knowledge transfer. This pattern aligns with ECLAC's identification of alternative innovation pathways in Latin America, suggesting that market networks provide system resilience. Key policy implications include leveraging supplier networks for technology transfer, developing integrated financing mechanisms, and creating shared testing infrastructure while preserving existing advantages of business dynamics.

Keywords: Innovation systems; social network analysis; commercial intermediation; business networks; emerging economies; bipartite networks.

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1. Introduction

Paraguay's business innovation system offers a valuable context for examining these structural dynamics. Despite limited formal R&D infrastructure, the country has maintained innovation activities through networks dominated by customer-supplier relationships rather than the university-industry collaborations typical of developed economies. This structural pattern merits systematic documentation, particularly given the growing recognition that small emerging economies may require different analytical frameworks than their larger counterparts. Comparative studies document similar fragmentation patterns across the region: Colombia shows negative scientific source effects (Escorcia et al., 2022), Ecuador reports 71% cooperation in information versus 40% in training (Rojas Loza et al., 2025), while Brazil and Mexico maintain stronger university-industry linkages (Dutrénit & Arza, 2010). However, systematic structural network analysis documenting commercial intermediation dominance and objective-specific fragmentation patterns remains absent for small economies like Paraguay, limiting understanding of how system architecture conditions innovation pathways in resource-constrained contexts.

This study focuses on Paraguay as a representative case of small Latin American economies facing similar structural constraints: limited institutional frameworks for innovation, weak university-industry

linkages (Paredes & Maldonado, 2022; Servín, 2016), and manufacturing-dominated productive structures. Unlike larger regional economies (Brazil, Mexico, Argentina) with more developed institutional coordination mechanisms (Dutrénit & Arza, 2010), small economies like Paraguay, Ecuador, Bolivia, and Uruguay exhibit extreme institutional fragmentation, making commercial intermediation patterns particularly pronounced. Understanding these dynamics provides insights applicable to similarly-structured contexts across Latin America and other developing regions.

Previous research on Latin American innovation systems has focused primarily on institutional weaknesses and policy gaps (Arocena & Sutz, 2000; Dutrénit & Arza, 2010), with limited attention to how commercial relationships operate as innovation intermediaries when formal institutions remain underdeveloped. Social network analysis provides tools to examine these patterns quantitatively, revealing structural properties and hierarchical relationships that traditional innovation surveys cannot capture.

This research contributes to JOTMI's sustained examination of innovation system architectures in Latin American emerging economies (Geldes & Castillo-Vergara, 2025; Ribeiro et al., 2022; Tamayo-Galarza et al., 2025), advancing understanding of how commercial relationships function as coordination mechanisms when formal institutional frameworks remain underdeveloped.

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This investigation documents the structural characteristics of Paraguay's business innovation system during the 2018-2020 period, providing a baseline for understanding how commercial intermediation operated before recent regional transformations. Using bipartite network analysis of comprehensive survey data, we examine: (1) What are the hierarchical structures of linkages within innovation systems? (2) What functional specializations emerge across different innovation objectives? (3) How can these findings inform innovation policy design in small emerging economies with similar structural characteristics?

2 Literature Review

2.1 Innovation Systems Theory: Neo-Schumpeterian Foundations

The neo-Schumpeterian tradition of innovation systems analysis, originating from Freeman (1987) and Lundvall (1992), challenges linear models by emphasizing systemic interactions between firms, institutions and organizations. This approach recognizes innovation as coordinated learning across organizational boundaries (Lundvall, 1992). Ahrweiler and Keane (2013) extend this perspective by proposing that innovation networks emerge from cognitive and social interactions, providing conceptual framework for understanding commercial actors as knowledge intermediaries. ECLAC (2022, p.13) emphasizes that addressing major national challenges requires 'coordination between various stakeholders (government, academia, the private sector and civil society)' and the establishment of 'new institutional arrangements' for capacity-building in policy formulation and management. This mission-oriented approach prioritizes applied research that mobilizes productive, technical and knowledge capacities to resolve specific challenges rather than relying solely on market-driven innovation models.

2.2 Innovation Linkages and Network Intermediation

Innovation linkages represent relational connections enabling knowledge flows between system actors. Howells (2006) defines these as intermediation processes facilitating knowledge creation, combination and exchange between organizations with different capabilities. In contexts where formal intermediary organizations (technology transfer offices, innovation agencies) remain weak, commercial relationships between firms and customers/suppliers may assume intermediation functions. This 'commercial intermediation' differs from formal brokerage by embedding knowledge exchange within transactional relationships, creating hybrid structures combining economic exchange with knowledge transfer (ECLAC, 2022). Del Carpio and Miralles (2021) demonstrate in Peruvian manufacturing that absorptive capacity mediates relationships between collaboration networks and technological innovation, with differentiated effects from connections with customers, suppliers, competitors, and research institutes. This conceptualization recognizes innovation emerges from systemic interaction rather than isolated actors.

Empirical evidence reveals differentiated impacts by linkage type. Un et al. (2010) demonstrate in USA and Japan that collaborations with universities and foreign firms generate stronger product innovation impacts than domestic firm partnerships, with absorptive

capacity moderating these effects. Giuliani (2007) provides critical Latin American evidence: linkages with knowledge institutions (universities, R&D centers) show greater impact on radical innovation, while customer-supplier linkages drive incremental innovation in Chilean, Argentine and Brazilian clusters. This functional differentiation suggests commercial-dominant systems may be structurally oriented toward incremental rather than radical innovation.

2.3 National Innovation Systems in Developing Contexts

The National Innovation Systems (NIS) concept emerged in the late 1980s, redefining innovation as interactive processes among public and private actors (Edquist, 1997; Freeman, 1987; Lundvall, 1992; Nelson & Rosenberg, 1993). Stuck et al. (2016) argue regional innovation systems research lacks theoretically precise and quantitatively measurable statements about inter-organizational structures, justifying social network analysis application.

In developing countries, particularly Latin America, specific challenges hinder adequate system functioning. Arocena and Sutz (2000) identify weak linkages between main actors, predominant incremental innovations, lack of coordinated policies, low R&D investment, and orientation toward foreign technology absorption. Goñi and Maloney (2014) demonstrate developing economies face decreasing returns on R&D investment due to absent critical complements: specialized human capital, research infrastructure, and sophisticated private sectors. Their findings reveal that for poor countries, exclusive R&D spending focus is insufficient without complementary efforts in organizing national innovation systems and strengthening actor interactions.

2.4 Empirical Evidence from Latin American Innovation Systems

Recent regional studies document systematic patterns distinguishing Latin American systems from developed country models. Escorcia et al. (2022) find in Colombia that firms depend primarily on internal and open-access sources for innovation, while scientific sources show negative effects on product innovation. This pattern indicates that even when firms access university knowledge, it fails to translate into innovation outcomes, revealing systematic barriers in university-industry knowledge transfer. In Ecuador, Rojas et al. (2025) found that firms cooperate primarily in information search (71%), technical assistance (47%), product testing (41%), and training (40%), with minimal R&D collaboration. Cevallos et al. (2024) demonstrate that cooperation in R&D, engineering, and technical assistance—but not in information search, product testing, or training—significantly enhances technological capabilities. These findings reveal that firms with higher capabilities engage in more complex activities, though low-complexity cooperation predominates, reflecting the regional tendency toward incremental over radical innovation.

Pasciaroni and Barbero (2020) identify in Argentina significant performance gaps favoring linked firms, particularly those with complex linkages, but these gaps are explained primarily by internal firm characteristics (innovation activities, external information sources) rather than direct linkage effects. Only in process innovation do complex linkages show positive impact, particularly for SMEs, suggesting linkage benefits are mediated by absorptive capacity.

Dutrénit and Arza (2010) demonstrate through comparative analysis of Argentina, Brazil, Mexico and Uruguay that university-industry-government linkages are unequal regionally, with greater intensity in Brazil and Mexico. This variation suggests institutional development levels condition possible relational architectures. Rapini (2007) documents in Brazil that most firms do not use formal linkages for innovation, with collaborations concentrated in large firms and universities more relevant for high-technology sectors.

ECLAC (2022) synthesizes these patterns, identifying “alternative innovation pathways” in Latin America where commercial networks provide system resilience when institutional mechanisms remain underdeveloped. This regional characterization validates studying market-driven innovation models as legitimate adaptive responses rather than institutional failures.

2.5 Social Network Analysis Applications in Innovation Research

Social network analysis provides quantitative measures of structural properties and relational patterns. Kastle and Steen (2010) establish that SNA offers fundamental tools for understanding how relational structures influence innovation performance, validating centrality metrics application to reveal innovation system hierarchies. Muller and Peres (2019) establish innovation growth is particularly effective in networks demonstrating cohesion, connectivity, and conciseness, validating structural network analysis for evaluating innovation systems.

Guerrero-Ocampo and Díaz-Puente (2023) demonstrate SNA effectiveness in resource-limited environments, where density and centrality measures capture how communities organize innovation activities when formal institutions are weak. Purbasari et al. (2023) validate SNA's capacity to reveal intermediation patterns in digital ecosystems, showing commercial relationships serve as primary knowledge transfer mechanisms in contemporary innovation systems.

Galaso et al. (2019) apply network analysis to Uruguayan manufacturing, finding firms with greater network centrality adopt “make” strategies (internal development) for radical innovation, while “buy” strategies (external acquisition) dominate incremental innovation. Network structure and firm position determine strategic options and innovation outcomes, confirming relational architecture importance.

2.6 Paraguay's Innovation System Context

Paraguay's innovation system exhibits typically Latin American characteristics: weak institutional coordination, limited private R&D investment, and insufficient university-industry collaboration (Servín, 2016). Angelelli et al. (2016) and Masi et al. (2021) document innovation determinants in Paraguayan companies, highlighting external knowledge sources and collaborative relationships importance.

Servín and Masi (2018) provide empirical evidence that productive system fragmentation patterns reflect territories differentiated capacity to articulate dense business networks, recognizing regional asymmetries emerge from historical processes of localized business capacity formation. Servín and Masi (2019) studied business cooperation

networks during 2016-2017, finding highly fragmented systems with fragile inter-sectoral connections. They identified crucial roles of intermediary organizations—business associations, governmental entities, and training institutions—in achieving network connectivity. While companies operate isolated within sectors, incorporating support organizations substantially improves connectivity.

Galaso et al. (2024) document in six Paraguayan manufacturing clusters (meat, dairy, ceramics, textiles, pharmaceuticals, chemicals) that companies access external resources through cluster support organizations, confirming intermediary organizations' systemic articulation role. Paredes and Maldonado (2022, 2023) provide updated characterizations of Paraguay's National Science, Technology and Innovation System (SNCTI), identifying persistent limitations in qualified human talent formation, scientific production, and weak university-industry linkages. However, these studies prioritize aggregate institutional analyses rather than relational structures between actors.

2.7 Research Gap and Contribution

While existing literature provides perspectives on emerging economy innovation systems, significant gaps remain in understanding actual network structures connecting companies with institutional actors. Most studies rely on aggregate indicators rather than detailed linkage pattern mapping. Regional studies document similar challenges (weak university linkages, commercial dominance, institutional fragmentation) but lack systematic structural comparison revealing common patterns versus country-specific characteristics.

This research addresses these gaps by applying social network analysis to comprehensive survey data from Paraguay's innovation system during 2018-2020, providing crucial baseline for understanding commercial intermediation operation before recent regional transformations. By analyzing bipartite networks representing different innovation objectives and comparing findings with regional evidence, this study provides quantitative insights into structural foundations likely continuing to influence Paraguay's innovation system evolution and validates whether identified patterns represent isolated cases or systematic regional characteristics requiring differentiated policy approaches. Recent JOTMI contributions advance understanding of these dynamics. Recent JOTMI contributions advance understanding of these dynamics. Gutiérrez et al. (2021) demonstrate through factor analysis of Chilean innovation survey data that networks and collaboration constitute the most important factor for sectoral patenting propensity, identifying three distinct sectoral innovation system configurations. Tamayo-Galarza et al. (2025) document in Chile that financial obstacles decrease over time while non-financial barriers (knowledge, cooperation, demand) gain relevance, providing temporal context for understanding the Financial Paradox observed in Paraguay where high formalization coexists with fragmentation. Ribeiro et al. (2022) demonstrate through network analysis of Brazilian SMEs that universities lead centrality in government-induced innovation networks, contrasting with the commercial-dominant pattern identified in resource-constrained contexts. Pellegrin et al. (2010) propose that Induced Innovation Networks become particularly relevant in less

mature innovation systems, validating the analytical framework applied here. These contributions establish JOTMI's sustained focus on innovation system architectures in emerging Latin American economies, to which this study contributes systematic documentation of commercial intermediation dominance and objective-specific fragmentation patterns in small economies.

ECLAC's (2022) call for coordination mechanisms between diverse stakeholders remains largely aspirational without empirical documentation of existing relational structures. While the report emphasizes that 'innovation is becoming a policy area involving all areas of government, which calls for new institutional arrangements that facilitate coordination' (p. 33), systematic analysis of how commercial relationships currently function as coordination mechanisms in the absence of formal institutional frameworks remains absent. This study addresses this gap by documenting the actual network structures through which Paraguayan firms access innovation-relevant knowledge, providing empirical foundation for understanding how market-based coordination operates when institutional mechanisms remain underdeveloped.

3. Methodology

3.1 Research Design

This research adopts a descriptive-analytical quantitative approach (Creswell & Creswell, 2017), using Social Network Analysis (SNA) methodology to examine linkage relationships between companies and actors within Paraguay's innovation system. The design is cross-sectional, based on secondary data obtained from the Encuesta de Innovación Empresarial del Paraguay (EIEP) corresponding to the 2018-2020 period.

3.2 Data Source

Data originates from the Encuesta de Innovación Empresarial del Paraguay (EIEP) 2018-2020, published in 2021 and available as open data on CONACYT's official web portal, constituting the official source of information on business innovation activities in Paraguay.

The EIEP 2021 was designed with a sample size of 776 companies. From visited companies, 675 were effectively surveyed, achieving an 87% response rate over the designed sample size, considered high according to Oslo Manual 2018 criteria, which classifies rates above 80% as high. Non-response (13% of sample) was primarily due to company closures during the reference period, refusal to provide information, companies not located at registered addresses, and absence of qualified informants.

Sample distribution shows 61.7% micro and small enterprises, 15.6% medium enterprises, and 22.7% large enterprises. Sectoral composition

includes 68.6% manufacturing and 31.4% services. This survey covers companies from different economic sectors and sizes, providing detailed information about their innovative activities and interaction with various actors within the national innovation system during the 2018-2020 period.

Institutional linkages are defined as agreements established by companies with different institution types (customers, consultants, competitors, suppliers, business associations, universities, R&D laboratories, and government institutions) for developing specific activities including R&D, engineering and design, training, technical assistance, information, product testing, and financing. These variables were constructed as dichotomous variables assuming value 1 if the company reported establishing linkages with the institution in question and 0 otherwise.

From the 675 surveyed companies, 378 (56%) reported establishing linkages with at least one institutional actor for innovation activities, constituting the final analytical sample for network construction. This subset represents actively linked firms within Paraguay's business innovation system during the analyzed period.

3.3 Justification and Construction of Bipartite Networks

3.3.1 Theoretical Foundation

A bipartite network is a special type of graph where nodes are divided into two disjoint sets (A and B), such that all edges connect nodes from different sets, with no connections existing within the same set (Wasserman & Faust, 1994; Latapy et al., 2008). This structure is particularly suitable for modeling linkage relationships between actors of different nature in innovation systems.

3.3.2 Network Structure

In this research:

Set A: Institutional actors of the innovation system (8 nodes):

- Customers
- Suppliers
- Consultants
- Government
- Universities
- Laboratories
- Competitors
- Professional or trade associations

Set B: Participating companies (variable according to the type of network analyzed)

Edges: Represent direct linkage relationships confirmed by participating companies

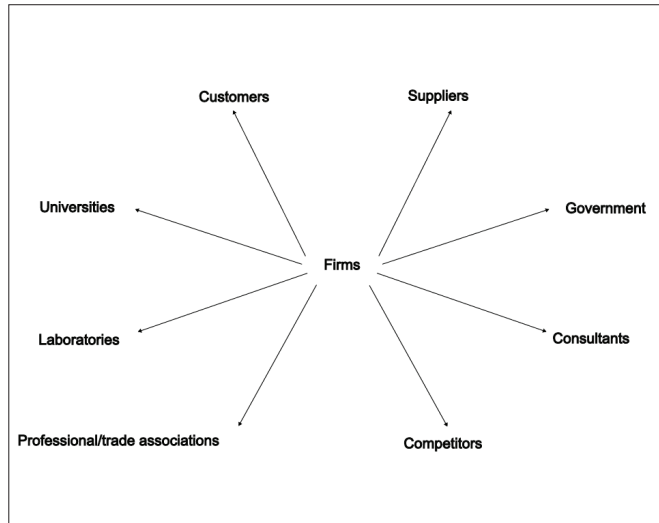
Figure 1. Actors and Linkages in the Innovation System

Figure 1 illustrates the conceptual structure of the bipartite network where companies (central node) establish linkages with the eight institutional actors of the innovation system. This configuration allows analyzing intermediation and centrality patterns in the Paraguayan system.

3.4 Construction of Analysis Networks

3.4.1 General System Network (R_1)

Base question: 'Did the company establish linkages with the following actors for innovation activities?'

Inclusion criteria: Affirmative response ('Yes') for linkage with at least one institutional actor

Nodes: Linked companies + Institutional actors with linkages

Edges: Company-actor connection when the company declares having established linkage

Interpretation: Represents the general structure of Paraguay's business innovation system

3.4.2 Objective-Specific Networks ($R_2 - R_9$)

Eight objective-specific networks are constructed: R&D, Engineering and Design, Training, Technical Assistance, Information, Product Testing, Financing, and Other Objectives. Each network includes companies reporting linkages for that specific objective and their connected institutional actors.

3.5 Sectoral Classification

Classification Base: International Standard Industrial Classification (ISIC Rev.4) at section level

Applied Aggregation:

- Manufacturing industries (Section C)
- Information and communications (Section J)
- Professional, scientific and technical activities (Section M)

Justification: Aggregation is necessary given the high number of specific economic activities reported and allows identification of clear sectoral patterns in participation.

3.6 Analysis Tools

Primary Software: Gephi 0.10.1 (Bastian et al., 2009) for:

- Construction and visualization of bipartite networks
- Calculation of centrality metrics and modularity
- Application of layout algorithms (ForceAtlas 2) (Jacomy et al., 2014)

Data Format: Edge list with structure:

- Source Column: Unique company ID
- Target Column: ID of linked actor
- Attributes: Sector (ISIC Classification), Size, Formalization.

3.7 Data Processing and Analysis

3.7.1 Data Cleaning and Preparation

Data processing involved filtering affirmative linkages, retaining only positive responses while excluding missing values and non-responses.

3.7.2 Matrix Construction

For each network, a binary adjacency matrix was constructed where rows represent companies and columns represent institutional actors, based exclusively on affirmative linkage responses reported by companies. Matrices were exported from Excel in Gephi-compatible format as node and edge lists including only confirmed connections.

3.8 Network Analysis Metrics

Social network analysis allows quantification of structural properties through specific metrics that reveal connectivity patterns (Newman, 2010). For bipartite networks, adapted metrics are calculated that consider the dual nature of nodes.

3.8.1 Global Network Metrics

Density = $E / (n_1 \times n_2)$, where E is total edges, n_1 is companies, n_2 is actors (8). Values range from 0-1.

Modularity: The Louvain algorithm adapted for bipartite networks is applied, with values between -1 and 1 (Newman, 2006). In bipartite company-actor networks, modularity captures the tendency of certain company groups to connect preferentially with specific subsets of institutional actors, indicating relational specialization rather than traditional communities.

Specific interpretation for this study:

Values > 0.3 indicate significant functional specialization patterns

Values > 0.5 suggest high segmentation with little overlap between groups

Technical limitation: Bipartite modularity tends to overestimate community structure due to connection restrictions between sets. Therefore, we interpret results as indicators of sectoral-functional specialization intensity rather than isolated communities.

3.8.2 Centrality Metrics

Three centrality measures are calculated for each institutional actor: eigenvector centrality, betweenness and closeness.

3.8.3 Additional Cohesion Metrics

Average path length

Represents the mean shortest distance between nodes, revealing information transmission efficiency across the system. Lower values indicate more direct connectivity, while higher values suggest transmission barriers requiring intermediary actors.

Connected components

Identify disconnected subgraphs, quantifying fragmentation degree; a single component indicates all nodes are reachable, while multiple components reveal isolated clusters. These metrics complement density and modularity by capturing global connectivity patterns and system-wide reachability beyond local clustering structures, which are not applicable to bipartite networks where companies connect only with institutions rather than each other.

3.8.4 Composition Analysis

Sectoral and company size composition analysis was conducted to identify:

- Sectoral distribution: Companies classified into three main sectors
- Size distribution: Representation of micro and small enterprises, medium enterprises, and large enterprises
- Linkage formalization level: Proportion of formalized linkages (with contracts/agreements), non-formalized linkages, and non-selected

3.9 Analytical Procedure

Analysis proceeds in three stages: (1) general network structural analysis, (2) examination of objective-specific networks, and (3) comparative analysis across networks.

3.10 Ethical Considerations and Validity

- Anonymized Data: Only numerical IDs were used for companies, preserving confidentiality.
- Construct Validity: Networks capture conceptually distinct dimensions of the innovation system participation process.
- Reliability: Data comes from official source (CONACYT) with standardized collection procedures.
- External Validity: Findings are generalizable to the context of Paraguay's innovation system during the analyzed period.

3.11 Methodological Limitations

1. Temporality: Data corresponds to the 2018-2020 period, limiting temporal generalization
2. Self-selection: Only companies that responded to the survey are included
3. Self-report: Information based on business declarations without external verification

4. Sectoral aggregation: ISIC classification reduces granularity of sectoral analysis

5. Causality: Cross-sectional design does not allow establishing causal relationships

6. Representativeness: Results limited to companies participating in the BIS

7. Bipartite structure: May over-simplify complex multi-actor and indirect relationships that contribute to business innovation processes

3.12 Potential Biases and Representativeness Considerations

Several methodological considerations may affect findings' interpretation. Self-selection bias is present as companies choosing to participate in innovation surveys likely demonstrate higher innovation propensities than non-respondents. The 13% non-response rate, while acceptable by Oslo Manual standards, may systematically exclude less structured or informal enterprises with weaker innovation capabilities.

Sectoral composition reveals potential bias: manufacturing represents 68.6% of the surveyed sample but only 65.58% of the final linked companies network, while the broader Paraguayan economy shows more balanced sectoral distribution. This manufacturing overrepresentation suggests findings may better characterize industrial innovation dynamics than service sector patterns.

The analytical sample (378 linked companies from 675 total) represents 56% of surveyed firms, indicating that nearly half of companies report no institutional linkages for innovation. This filtering creates survivor bias where analyzed networks represent upper bounds of actual system connectivity rather than typical business behavior. Results should be interpreted as characteristics of actively innovating and explicitly linked firms rather than the entire business population.

Self-reported data without external verification may introduce reporting bias, particularly for commercially sensitive information regarding financial relationships and competitive interactions. Companies may under-report informal linkages lacking formal contracts, potentially underestimating the true extent of knowledge transfer through tacit channels.

Geographic concentration effects are present but unquantified in available data, as the sample includes firms across Paraguay's regions without explicit regional stratification in network analysis. Given documented territorial development asymmetries (Servín & Masi, 2018), findings may predominantly reflect dynamics in more developed central regions rather than peripheral areas.

The bipartite network structure, while theoretically appropriate for company-institution analysis, necessarily excludes company-to-company networks and indirect relationships through intermediaries that may facilitate innovation diffusion. This structural simplification may underestimate systemic connectivity operating through horizontal business networks documented in cluster studies (Galaso et al., 2024).

These limitations suggest results characterize innovation system structure for actively innovating firms with explicit institutional linkages during 2018-2020, providing conservative estimates of system connectivity while potentially overestimating innovation intensity relative to the broader business population.

4. Results

4.1 General Network Structure

Figure 2. General Structure of Paraguay's Business Innovation System Bipartite Network (2018-2020)

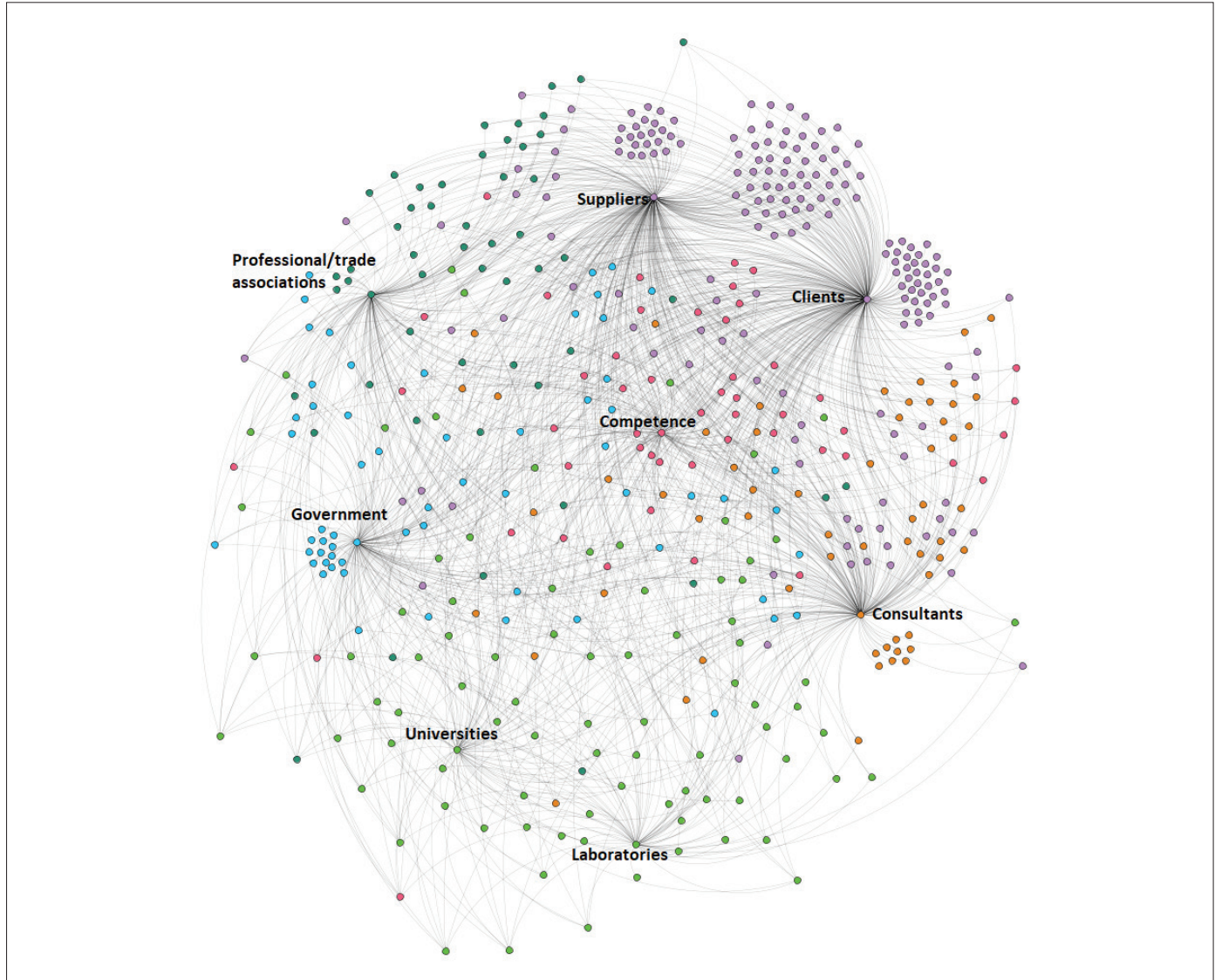


Figure 2. Visualization of Paraguay's business innovation system bipartite network during the 2018-2020 period. The network includes 378 companies (small nodes) connected with 8 institutional actors (central labeled nodes): Customers, Suppliers, Consultants, Government, Universities, Laboratories, Professional/trade associations, and Competitors. The ForceAtlas 2 layout positions nodes according to their connectivity, revealing the system's hierarchical structure. Commercial actors (Customers and Suppliers) occupy central positions, while knowledge institutions (Universities and Laboratories) appear in peripheral positions. The density of 0.012 and modularity of 0.203 indicate a system with strategic selective relationships and the presence of

six distinct communities. Edges represent confirmed linkages between companies and institutional actors for innovation activities. Paraguay's business innovation system general network exhibits a density of 0.012, indicating relatively dispersed connectivity where companies establish selective strategic relationships rather than broad connections.

Modularity analysis revealed a value of 0.203, identifying six distinct communities (classes 0-5) within the network. This intermediate modularity suggests a structure between complete fragmentation and total integration, indicating the presence of cohesive subgroups while

maintaining overall system coherence. This community segmentation indicates that, despite low general density, there are actor clusters that maintain more intensive connections among themselves. The general system's modularity of 0.203 indicates moderate specialization: while companies tend to concentrate their linkages on specific subsets of actors (forming the six identified communities), sufficient overlap

exists to maintain systemic cohesion. This configuration suggests an adaptive balance where companies can access specialized resources without completely fragmenting the system.

Table 1 presents the comprehensive structural characteristics of the innovation system's general network.

Table 1. General Innovation System Network Structure

Metric	Value	Interpretation
Total Companies	378	Total participating companies in the general network
Total Actors	8	Institutional actors: Customers, Suppliers, Consultants, Government, Universities, Laboratories, Professional/trade associations, Competitors.
Density	0.012	Low connectivity indicating selective strategic relationships
Modularity	0.203	Intermediate fragmentation with 6 distinct communities
Avg Path Length	2.354	Efficient information transmission
Connected Components	1	Fully connected system
Communities	6	Classes 0-5 showing cohesive subgroups
Manufacturing	65.58%	Dominant sectoral participation
Information & Communications	25.42%	Secondary sectoral participation
Professional Services	9.0%	Tertiary sectoral participation
Micro & Small Enterprises	53.6%	Predominant company size category
Medium Enterprises	18.42%	Intermediate company size representation
Large Enterprises	27.98%	Significant large company participation

4.2 Actor Hierarchy and Centrality

Network analysis reveals a clear hierarchical structure among the eight institutional actors. Customers emerge as the most influential actor with perfect eigenvector centrality (1.0), the highest betweenness centrality (0.4279), and closeness centrality (0.658). This dominance indicates that customer relationships drive innovation activities and serve as primary conduits for information flow within the system.

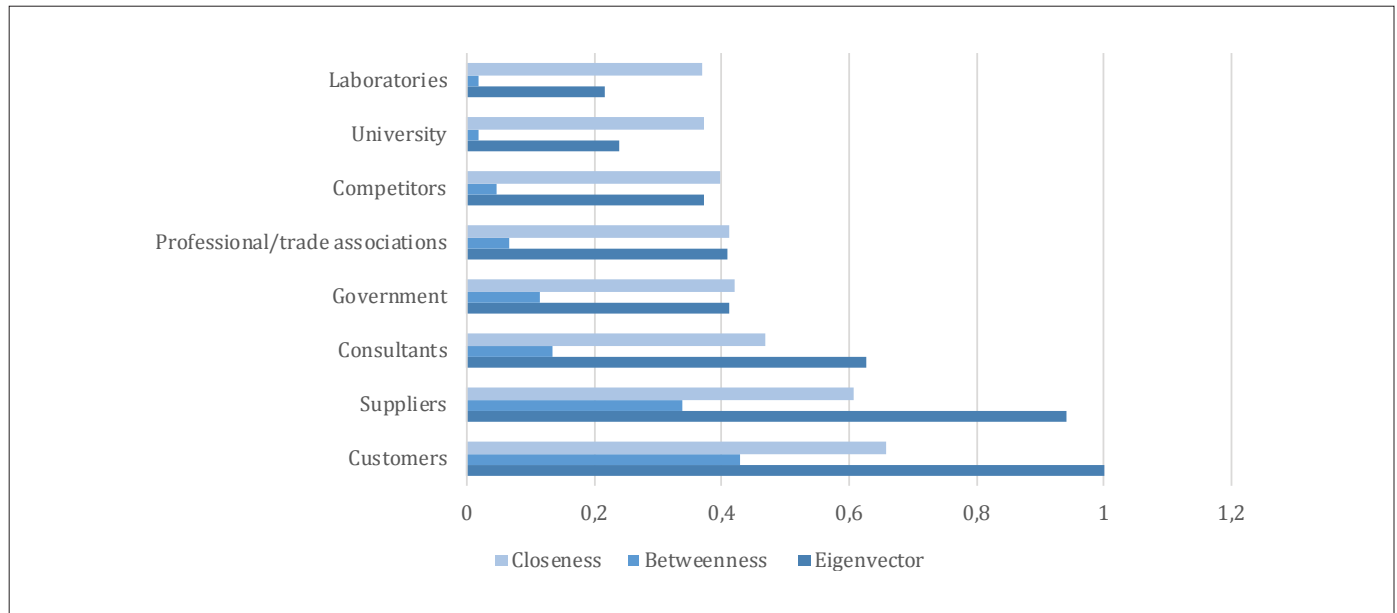
Suppliers occupy the second position in the hierarchy with eigenvector centrality of 0.94, betweenness centrality of 0.3383, and closeness centrality of 0.6076. The strong positioning of both Customers and Suppliers creates a bilateral commercial dynamic that forms the operational core of the innovation system.

Consultants present eigenvector centrality of 0.6261, positioning them as relevant actors with moderate intermediation capacity (0.1358) and closeness (0.4676). Government shows eigenvector centrality of 0.4123 with moderate betweenness (0.1147) and closeness (0.4196), suggesting an important but not dominant institutional role.

Professional associations register eigenvector centrality of 0.4095 with low betweenness (0.066) and closeness (0.4112), indicating a sectoral representation role with limited capacity for knowledge flow intermediation. Competitors presents eigenvector centrality of 0.3724 with moderate betweenness (0.0456) and closeness (0.3991), reflecting less frequent but strategically relevant linkages.

Universities and Laboratories occupy peripheral positions with eigenvector centralities of 0.2387 and 0.2174 respectively. Their low betweenness metrics (0.0191 and 0.018) and closeness (0.3731 and 0.3702) suggest specialized roles with limited integration in daily business innovation dynamics.

Figure 3. Centrality Measures Comparison



The hierarchical structure becomes evident when comparing the three centrality measures across institutional actors (Figure 3).

Figure 3. Comparison of centrality measures across institutional actors in Paraguay’s business innovation system. The grouped bar chart displays eigenvector centrality (dark blue), betweenness centrality (medium blue), and closeness centrality (light blue) for each actor. Customers and Suppliers demonstrate dominance across all centrality measures, while Universities and Laboratories show consistently low values, confirming their peripheral positions in the network structure.

4.3 Sectoral Composition

The system shows strong sectoral concentration with manufacturing industries representing 65.58% of network participants, followed by information and communications (25.42%) and professional, scientific and technical activities (9.0%). This distribution reflects Paraguay’s industrial structure while highlighting the growing importance of knowledge-intensive services.

Company size distribution reveals predominance of micro and small enterprises (53.6%), followed by large companies (27.98%) and medium enterprises (18.42%). This pattern is typical of emerging economies where smaller-scale business structures dominate while larger firms maintain significant network influence.

4.4 Objective-Specific Network Analysis

Analysis of eight objective-specific networks reveals differentiated structural patterns and significant variation in connectivity and fragmentation levels (Table 2). Density varies considerably across objectives: R&D presents the highest connectivity (density 0.030), while Product Testing, Training and Technical Assistance maintain densities similar to the general network (0.012). Financing shows intermediate density (0.024).

Modularity presents an inverse pattern: all objectives exhibit greater fragmentation than the general network (0.203), with Financing most fragmented (0.554, seven communities). This reveals a critical paradox: highest formalization (74.79%) coexists with maximum fragmentation, indicating formal instruments operate as isolated compartments rather than bridges. Different company types access completely distinct financial sources—microenterprises use micro-finance, medium firms commercial banks, large firms capital markets—with no effective cross-segment intermediation. Unlike other objectives where commercial actors bridge communities, financing lacks connecting mechanisms; specialized institutions maximize homogeneous portfolios, reinforcing segmentation. Longest average path (3.296 vs 2.354 general) confirms structural barriers between financial communities.

Differential modularity patterns reveal critical functional specializations:

- Financing (0.554): High fragmentation indicates systemic access barriers where different types of companies access completely distinct financial sources, creating silos without integration
- R&D (0.412): Intermediate-high modularity suggests that knowledge-intensive collaborations require specific compatibilities between companies and actors
- Information (0.336): Lower fragmentation indicates that information flows operate more transversally among different types of companies

This variation confirms that different innovation objectives require differentiated relational architectures, with direct implications for intervention policy design.

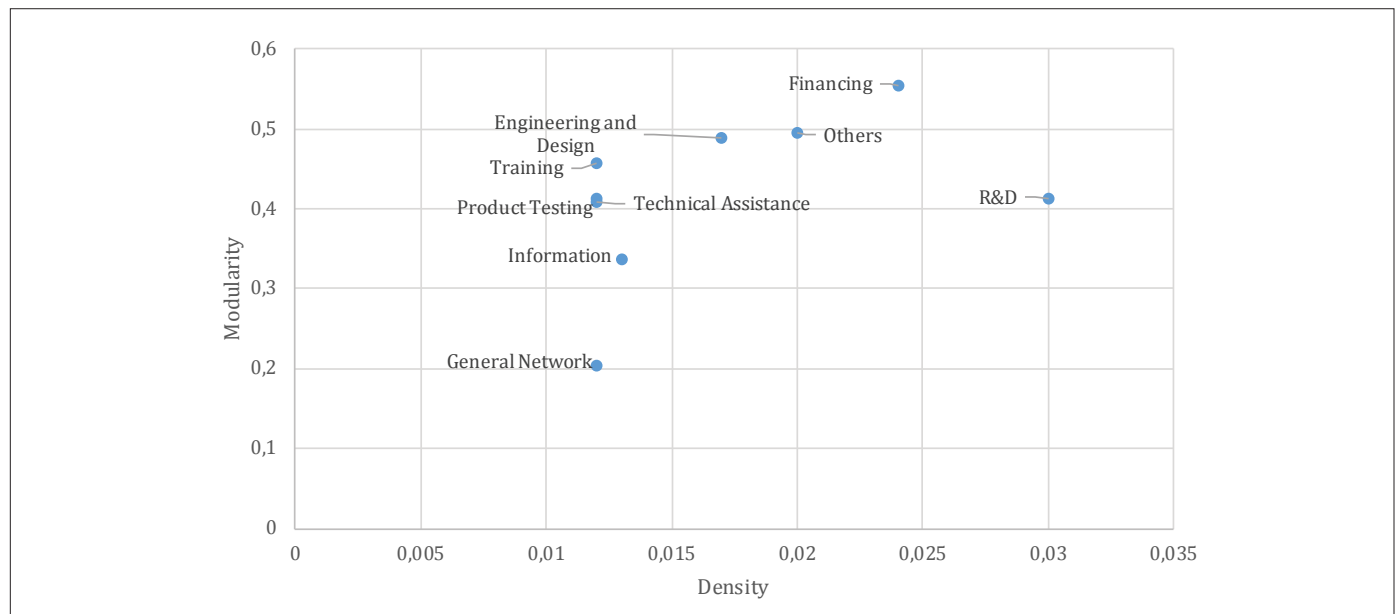
Path length analysis reveals efficiency variation in knowledge transmission. Financing networks exhibit the longest average path (3.296), confirming that high fragmentation (modularity 0.554) creates structural barriers to information flow. Conversely, Product Testing shows shortest path (2.718) despite similar density to other networks (0.012), suggesting more direct connectivity patterns. R&D networks

maintain intermediate path length (2.941) despite highest density (0.030), reflecting the influence of specialized communities requiring longer transmission routes between clusters. All networks maintain single connected components, indicating that despite functional fragmentation, basic system-wide connectivity is preserved.

Table 2. Network characteristics by innovation objective

Objective	Companies	Density	Modularity	Communities	Avg Paths	Components
R&D	105	0.030	0.412	7	2.941	1
Engineering & Design	157	0.017	0.488	6	3.033	1
Training	256	0.012	0.457	7	3.138	1
Technical Assistance	126	0.012	0.409	8	2.923	1
Information	315	0.013	0.336	7	2.854	1
Product Testing	238	0.012	0.412	6	2.718	1
Financing	92	0.024	0.554	7	3.296	1
Others	145	0.020	0.495	8	3.244	1

Figure 4. Network Characteristics by Innovation Objective



The relationship between density and modularity across objective-specific networks reveals distinct structural patterns (Figure 4).

Figure 4. Scatter plot comparing density (x-axis) and modularity (y-axis) across different innovation objective networks. Each point represents a specific network: R&D (highest density, moderate modularity), Financing (moderate density, highest modularity), and others distributed between these extremes. The general innovation system network is highlighted for reference. Bubble size indicates the number of participating companies in each network.

Sectoral Composition by Objectives

Sectoral composition reveals distinctive patterns between manufacturing and knowledge-intensive business services (KIBS).

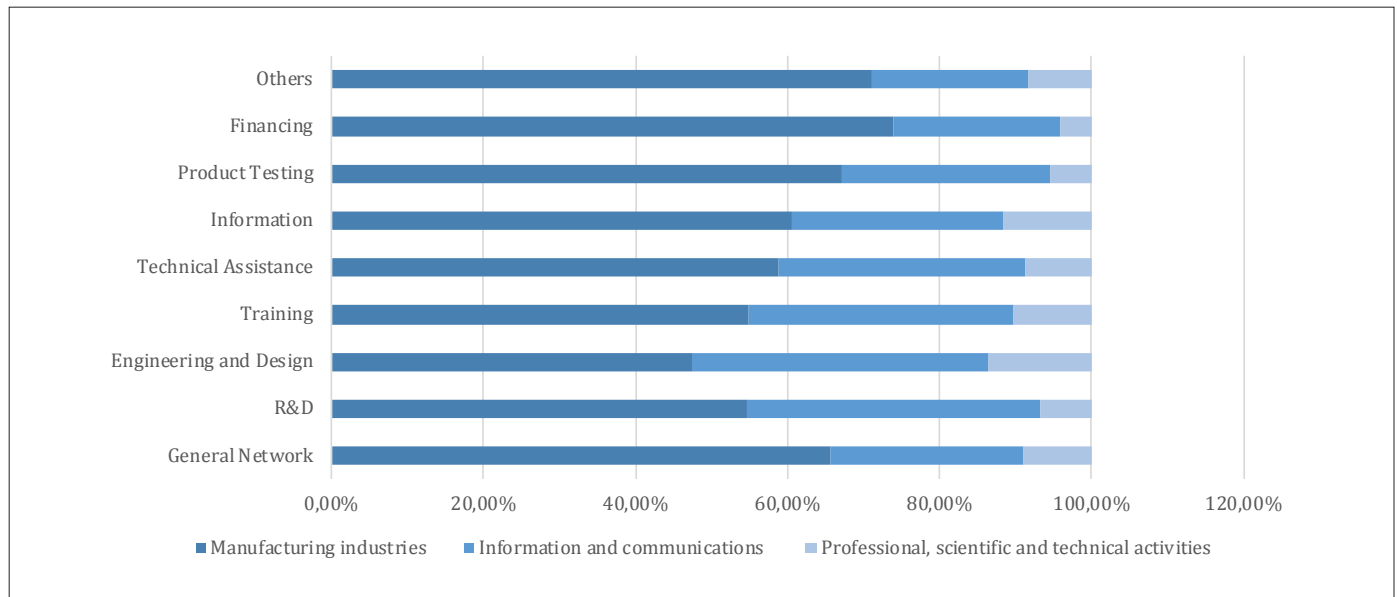
Manufacturing dominates Financing (73.95%) and Product Testing (67.20%), reflecting capital-intensive processes. Information and Communications shows disproportionate R&D participation (38.42% vs 25.42% system representation) and Engineering and Design (38.89%), indicating knowledge-intensive specialization.

The Commercial Intermediation Model operates with distinct sectoral mechanisms. Manufacturing's Product Testing concentration (67.20%) and lower R&D participation (54.29% despite 65.58% system presence) indicates supplier-driven incremental innovation through equipment-embodied technology. KIBS' R&D overrepresentation (38.42% + 13.01% professional services = 51.43% combined vs 34.42% system representation) suggests customer co-creation dynamics where clients function as development part-

ners in software and digital solutions—qualitatively distinct from manufacturing’s technology adoption model. The model exhibits sectoral heterogeneity: manufacturing operates through supplier

networks facilitating incremental improvements, while KIBS leverages customer networks for collaborative knowledge generation.

Figure 5: Sectoral Distribution by Innovation Objective



Sectoral specialization patterns become apparent when examining participation across objective-specific networks (Figure 5).

4.5 Linkage Formalization Patterns

Analysis of eight specific objective networks reveals differentiated structural patterns and significant variation in connectivity and fragmentation levels. Financing networks show the highest formalization rate (74.79% with contracts or formal agreements), reflecting the regulatory and legal requirements inherent in financial relationships (Table 3).

R&D networks demonstrate moderate-to-high formalization (68.42%), indicating that research and development collaborations

often require formal structures to protect intellectual property and define responsibilities.

Information networks show the lowest formalization rate (59.04%), suggesting that information exchange frequently occurs through informal channels and relationships.

The predominance of non-formalized linkages across most objectives (ranging from 20.17% to 32.53%) highlights the importance of informal networks and trust-based relationships in Paraguay’s innovation ecosystem.

Table 3. Company size distribution by innovation objective and linkage formalization status

Objective	Micro & Small	Medium	Large	Formalized	Non-formalized	Unselected
R&D	40.0%	20.0%	40.0%	68.42%	25.26%	6.32%
Engineering & Design	52.14%	16.24%	31.62%	71.37%	22.22%	6.41%
Training	50.84%	20.00%	29.16%	70.84%	21.45%	7.71%
Technical Assistance	50.61%	19.67%	29.71%	64.34%	26.43%	9.22%
Information	55.27%	18.67%	26.05%	59.04%	32.53%	8.43%
Product Testing	54.30%	16.40%	29.30%	65.05%	29.84%	5.11%
Financing	38.66%	26.05%	35.29%	74.79%	20.17%	5.04%
Others	48.25%	22.37%	29.39%	67.54%	27.19%	5.26%

Note: Formalized = Linkages with contracts or formal agreements; Non-formalized = Informal linkages without contracts; Unselected = No response or not applicable.

5. Discussion

5.1 Empirical Validation of Paraguay's Innovation System: Temporal Continuity and Structural Patterns

The findings reveal patterns partially consistent with Servín and Masi (2019): network fragmentation persists, with weak direct inter-firm cooperation. However, a critical difference emerges: while Servín and Masi identified institutional organizations (business associations, governmental regulatory entities, and training institutions) as key connectivity brokers within sectoral networks based on 2015–2016 data, the present study (2018–2020) reveals market actors (Customers and Suppliers) as dominant network intermediaries in innovation ecosystems.

This divergence likely reflects different analytical scopes. Servín and Masi examined formal cooperation activities (joint marketing, training programs, joint purchasing, R&D collaboration) within seven industrial sectors, while this study captures innovation-related relationships across broader ecosystems including supply chain interactions. The observed density (0.012) and modularity (0.203) confirm architectural continuity in network fragmentation, representing efficient adaptation to resource constraints where companies concentrate relational investments strategically on critical market relationships rather than dispersing efforts across institutional cooperation channels.

5.2 The Commercial Intermediation Model: Theoretical Foundation and Empirical Validation

Analysis reveals a 'Commercial Intermediation Model' where market actors dominate network centrality, contrasting with institutionally-led models typical of developed countries. Customers achieve perfect eigenvector centrality (1.0) while Suppliers occupy the second position (0.94), creating a bilateral commercial dynamic that forms the operational core of the innovation system. In contrast, Universities (0.2387) and Laboratories (0.2174) remain peripheral.

This finding aligns with ECLAC's (2022) identification of alternative knowledge transfer pathways in Latin American innovation systems, where commercial networks provide resilience when institutional mechanisms remain underdeveloped. Geldes and Castillo-Vergara (2025) emphasize that innovation remains "a major pending issue" for Latin American development, requiring understanding of actual relational structures rather than aspirational institutional frameworks. The model is characterized by three structural properties: (1) market actors serving as primary knowledge intermediaries, (2) functional specialization through formation of objective-differentiated sub-networks, and (3) academic institutions occupying specialized rather than central positions.

5.3 Support Organizations and Manufacturing Specialization

Manufacturing concentration in Product Testing (67.20%) and Financing (73.95%) reflects sectoral diversity requiring specialized technical capabilities, as documented by Galaso et al. (2024) in Paraguayan clusters. This specialization pattern reveals functional differentiation where traditional manufacturing activities rely heavily on infrastructure-dependent services.

Institutional specialization is confirmed through objective-specific analysis: Laboratories, despite peripheral position in the general network (centrality 0.2174), achieve greater prominence in Product Testing networks where technical validation capabilities become critical. This functional repositioning demonstrates that peripheral actors can assume strategic roles in specific innovation contexts.

The high formalization rate in Financing networks (74.79%) contrasts with lower formalization in Information exchanges (59.04%), suggesting regulatory requirements shape relationship structures more strongly in capital-intensive activities. Manufacturing firms' concentration in formalized financial linkages reflects both regulatory compliance needs and strategic resource acquisition patterns characteristic of capital-intensive production processes.

5.4 Structural Implications: Density, Modularity and System Efficiency

The observed network architecture—low density (0.012) combined with intermediate modularity (0.203)—reflects systemic adaptation to limited resource conditions. Density variation across specific objectives (0.012 in Product Testing to 0.030 in R&D) provides empirical evidence for functional specialization, where different types of innovation activities require differentiated relational intensities. Financing fragmentation (0.554) reveals a High fragmentation in Financing networks (modularity 0.554, seven communities) reveals a "Financial Paradox": the highest formalization rate (74.79%) coexists with maximum systemic fragmentation, challenging conventional assumptions where greater formalization should correlate with integration. This pattern aligns with Tamayo-Galarza et al.'s (2025) finding in Chile that financial obstacles evolve distinctly from non-financial barriers—while financial constraints may decrease through formalization, structural segmentation persists through three mechanisms: (1) exclusive institutional specialization where structural company characteristics determine access to completely distinct financial sources, (2) differentiated requirements functioning as exclusionary barriers where formal contracts (guarantees, credit histories, minimum volumes) institutionalize compartmentalization rather than facilitate cross-segment mobility, and (3) absence of effective financial intermediation where specialized institutions maximize homogeneous portfolios for risk management, preventing bridge formation between segments.

5.5 Sectoral Specialization and Evolutionary Capabilities

Differential sectoral composition across specific networks reveals emerging evolutionary capabilities. High participation of Information and Communications sectors in R&D (38.42%) and Engineering and Design (38.89%), despite representing only 25.42% of the total system, indicates sectoral specialization in knowledge-intensive activities that could serve as a systemic modernization engine. However, sectoral analysis reveals the Commercial Intermediation Model operates through differentiated mechanisms. KIBS firms' R&D overrepresentation (38.42% vs 25.42%) reflects customer co-creation where dominant customer centrality (1.0) enables collaborative knowledge generation—distinct from manufacturing's supplier-driven incremental improvement (centrality 0.94) through equipment

acquisition. This aligns with Pavitt's (1984) taxonomy distinguishing supplier-dominated sectors from specialized suppliers, suggesting the model adapts to sectoral innovation regimes. Professional services in Engineering and Design (13.68%) could bridge manufacturing-KIBS logics, facilitating cross-sectoral knowledge transfer. This pattern contrasts with manufacturing dominance in traditional activities (Product Testing 67.20%, Financing 73.95%), suggesting coexistence of established industrial capabilities with emerging capabilities in knowledge-intensive services. Sectoral differentiation provides empirical foundation for targeted innovation policies that leverage existing specializations while fostering evolutionary capabilities. Concentration of professional services companies in Engineering and Design (13.68%) confirms emergence of specialized technical capabilities that complement both traditional manufacturing and emerging digital capabilities. This diversification indicates potential for developing a more sophisticated innovation ecosystem based on existing sectoral complementarities. This sectoral specialization pattern aligns with Gutiérrez et al.'s (2021) identification of three distinct sectoral innovation system configurations in Chile, where networks and collaboration emerge as the most important factor differentiating sectoral propensity to patent. The Paraguayan case extends this regional evidence by documenting how sectoral differentiation operates through commercial intermediation mechanisms when formal institutional frameworks remain underdeveloped.

This finding resonates with Boisier et al.'s (2021) structural-functional analysis of Chilean dairy sector, where technology adoption patterns differed between traditional production and knowledge-intensive precision agriculture, confirming sectoral heterogeneity within emerging economy innovation systems documented by JOTMI research.

5.6 Regional Contextualization of the Commercial Intermediation Model

The dominant commercial intermediation pattern identified in Paraguay reflects structural characteristics shared across Latin American innovation systems, with significant variations in intensity and institutional configuration.

Regional Structural Similarities

The peripheral position of scientific institutions in Paraguay (universities 0.2387, laboratories 0.2174 centrality) finds direct empirical validation across neighboring countries. Escorcia et al. (2022) document negative effects of scientific sources on product innovation in Colombia, suggesting systematic university-industry collaboration barriers transcending national contexts. In Ecuador, Rojas et al. (2025) 71% of firms cooperate in information search while only 40% participate in training, proportions similar to Paraguay's Information network density (0.013) versus R&D (0.030). Cevallos et al. (2024) report confirm Ecuadorian firms "cooperate more in activities like information search and technical assistance, and less in advanced activities like R&D."

Systemic fragmentation with specialized community formation characterizes regional innovation systems. Pasciaroni and Barbero (2020)

identify in Argentina significant gaps between linked and non-linked firms, where positive effects of complex linkages concentrate in process innovation and are mediated by internal capabilities. This relational selectivity aligns with Paraguay's intermediate modularity (0.203) indicating functional specialization without complete fragmentation.

Critical Differences and Relative Positioning

Comparative analysis reveals Paraguay represents an extreme case within the Latin American spectrum of institutional fragmentation. Dutrénit and Arza (2010) document unequal university-industry-government linkages regionally, with greater intensity in Brazil and Mexico where more developed institutional structures facilitate formal collaborations. Giuliani (2007) provides particularly relevant evidence analyzing clusters in Chile, Argentina, and Brazil, where linkages with knowledge institutions show greater impact on radical innovation while commercial linkages predominate in incremental innovation. This functional differentiation explains Paraguayan model implications: commercial dominance provides capabilities for incremental innovation and technology adoption but limits potential for radical innovation requiring more intensive scientific linkages.

Del Carpio and Miralles (2021) document in Peru that absorptive capacity mediates relationships between collaboration networks and technological innovation, illuminating Consultants' role in Paraguay (centrality 0.6261, betweenness 0.1358) as knowledge translators in systems with limited institutional absorptive capacity.

Theoretical Implications

Regional empirical convergence validates ECLAC's (2022) proposal of "alternative knowledge transfer pathways" in Latin America, where commercial networks provide systemic resilience when institutional mechanisms remain underdeveloped. However, comparative studies reveal structural limits: Rapini (2007) demonstrates in Brazil that even in larger economies, most firms do not use formal linkages for innovation, though high-technology sectors establish strategic university collaborations—capacity absent in current Paraguayan structure.

Regional evidence suggests the commercial intermediation model represents an efficient adaptive solution for initial industrial development stages but requires evolution toward more complex configurations to sustain transitions toward knowledge-intensive sectors. High Information and Communications sector participation in Paraguayan R&D networks (38.42% versus 25.42% general representation) indicates emerging capabilities that could catalyze this transition.

6. Conclusions

This research documents the structural characteristics of Paraguay's business innovation system during the 2018-2020 period, establishing an empirical baseline for understanding commercial intermediation dynamics in small emerging economies. The analysis reveals patterns confirming theoretical expectations for developing country innovation systems while identifying specific opportunities for systemic improvement.

6.1 Academic Implications

The study provides three substantive contributions to innovation systems literature. First, it documents empirically the “dominant commercial intermediation” pattern where market actors (Customers with perfect eigenvector centrality 1.0, Suppliers 0.94) substitute traditional institutional linkages as primary knowledge transfer mechanisms. This pattern, validated across Latin American contexts (Cevallos et al., 2024; Escorcía et al., 2022), challenges institutional frameworks developed for advanced economies and supports ECLAC’s (2022) identification of alternative innovation pathways in the region.

Second, the application of bipartite network analysis with objective-specific decomposition reveals differentiated relational architectures: R&D networks exhibit higher connectivity (density 0.030) while Financing shows severe fragmentation (modularity 0.554). This methodological contribution demonstrates that aggregated system metrics obscure critical functional specializations requiring targeted interventions.

Third, temporal continuity with previous Paraguayan studies (Servín & Masi, 2018-2019) confirms stability in structural patterns. Earlier research documented territorial development disparities where dynamic productive regions coexisted with weak business networks, particularly in frontier zones where agricultural modernization failed to generate dense entrepreneurial ecosystems (Servín & Masi, 2018:91-92). This suggests the commercial intermediation model observed in the present study represents an adaptive equilibrium for resource-constrained contexts rather than transitional dysfunction. The observed density (0.012) and modularity (0.203), combined with the identification of six distinct communities, indicate functional specialization without complete systemic fragmentation—a pattern consistent with market-based coordination mechanisms dominating over institutional cooperation channels.

6.2 Business Management Implications

Network structure analysis provides actionable guidance for innovation managers. Manufacturing companies (65.58% of system) should prioritize supplier development programs given high supplier centrality (0.94), as joint development investments generate greater returns than academic collaborations in this configuration. Their specialization in product testing (67.20% participation) suggests significant opportunities for peer-based interactive learning.

Information and communications companies, despite representing 25.42% of the system, show disproportionate R&D participation (38.42%), indicating comparative advantages in knowledge-intensive collaborations. These firms can leverage digital capabilities to serve as innovation intermediaries between traditional actors and emerging technology providers.

For micro and small enterprises (53.6% of system), low general density (0.012) necessitates concentrated relational investments on two to three strategic linkage types, using existing commercial relationships as bridges toward technical capabilities. Large companies (27.98%) can assume systemic articulation roles, serving as anchors for smaller firms through diversified innovation strategies.

Effective linkage portfolio management requires specialization by objective: consultants and competitors for R&D (leveraging consultant centrality 0.6261), sector-specific financial suppliers addressing identified fragmentation, and specialized laboratories for testing where institutional positioning improves (versus general peripheral position).

6.3 Policy Implications

Policy design must recognize both the functionality of the current commercial-dominant model and its structural limitations for radical innovation. Rather than attempting to replicate university-industry models from developed countries, interventions should strengthen existing commercial relationships as innovation channels while gradually developing institutional capabilities.

Priority interventions include:

Financial architecture transformation: The Financial Paradox—highest formalization (74.79%) with maximum fragmentation (0.554)—reveals formal contracts operate as compartments institutionalizing segmentation. Interventions require cross-segment intermediation mechanisms: (1) co-financing funds requiring joint institutional participation forcing bridge creation, (2) shared information platforms reducing asymmetries justifying segmentation, (3) progressive cross-guarantees enabling continuity when companies migrate segments, (4) trans-segment second-tier institutions incentivizing collaboration over competition. These transform formal instruments from segmentation devices into integration infrastructure.

Technology transfer through suppliers: Leverage suppliers’ high centrality (betweenness 0.3383) for technology transfer programs, designing incentives for joint innovation projects between buyers and suppliers and technical assistance programs utilizing commercial networks as delivery channels.

Shared infrastructure development: Create shared testing infrastructure serving manufacturing sector needs (67.20% participation in testing networks), addressing identified gaps while respecting functional specializations through neutral platforms for multi-actor collaboration.

Strategic university-industry linkages: Foster academic collaborations specifically in R&D networks where greater natural connectivity exists (density 0.030), positioning universities as specialized service providers within commercial innovation networks rather than competing with commercial actors.

Cross-sectoral platforms with sectoral differentiation: Leverage Information and Communications R&D specialization (38.42% vs 25.42% representation) recognizing KIBS innovation operates through customer co-creation distinct from manufacturing’s supplier-driven model. Policies should: (1) develop manufacturing-KIBS bridges through professional services (13.68% Engineering and Design), (2) create client-oriented platforms for KIBS supporting collaborative contracts, (3) design supplier development for manufacturing leveraging equipment-embodied technology, (4) establish digital transformation where KIBS modernize manufacturing. This respects sectoral heterogeneity within Commercial Intermediation.

Policy implementation should follow phased approach: first, strengthen existing commercial relationships through targeted support; second, develop integrated financing mechanisms; third, create shared infrastructure; finally, establish platforms for cross-sectoral knowledge transfer. Success metrics should focus on network connectivity improvements and financing fragmentation reduction rather than traditional R&D investment indicators alone.

6.4 Study Limitations and Future Research

Cross-sectional design limits temporal generalization and causal inference. Data corresponds to 2018-2020 period, preceding recent regional transformations. Self-reported survey data without external verification may introduce bias, while bipartite structure potentially over-simplifies complex multi-actor dynamics. Results are specific to companies participating in the business innovation system, limiting broader representativeness.

Future research should examine temporal evolution of network structures, investigate specific knowledge transfer mechanisms through commercial relationships, and analyze how policy interventions affect structural properties. Comparative analysis with other small emerging economies (Ecuador, Uruguay, Bolivia) could provide insights into effective structural configurations for countries with similar characteristics. Longitudinal studies would enable measuring innovation policy impacts and tracking system evolution toward more sophisticated configurations.

Regional evidence suggests the commercial intermediation model represents efficient adaptive solutions for initial industrial development stages but requires evolution toward more complex configurations to sustain transitions toward knowledge-intensive sectors. Understanding these evolutionary pathways remains critical for contemporary innovation policy design in resource-constrained contexts.

7. Practical Implications

The structural analysis provides actionable guidance for business managers, policymakers, and support organizations based on identified commercial intermediation patterns and functional specialization.

7.1 Business Management Implications

Manufacturing companies (65.58% of system) should prioritize supplier development programs given high supplier centrality (0.94), as joint investments generate greater returns than academic collaborations. Specialization in product testing (67.20%) suggests opportunities for peer-based learning, while high financing fragmentation requires strategic identification of appropriate financial clusters.

Information and communications firms, despite 25.42% system representation, show disproportionate R&D participation (38.42%), indicating comparative advantages in knowledge-intensive collaborations. These companies can leverage digital capabilities to serve as innovation intermediaries between traditional and emerging sectors. Micro and small enterprises (53.6%) should concentrate resources on two to three strategic linkage types given low system density (0.012), using commercial relationships as bridges toward technical capabilities.

Large companies (27.98%) can assume network orchestration roles, serving as anchors through diversified innovation strategies. Effective portfolio management requires objective-specific specialization: consultants for R&D, sector-specific financial suppliers, and specialized laboratories for testing.

7.2 Policy Design Implications

Rather than replicating university-industry models from developed countries, policymakers should strengthen existing commercial relationships as innovation channels. Technology transfer programs should work through commercial networks given high customer-supplier centrality.

Priority interventions include: (1) integrated financing mechanisms bridging identified silos (modularity 0.554) through sector-specific innovation funds and collaborative financing instruments leveraging commercial relationships; (2) supplier development programs incentivizing joint innovation projects between buyers and suppliers; (3) shared testing infrastructure serving manufacturing needs (67.20% participation) through neutral multi-actor platforms; (4) strategic university-industry linkages in R&D networks where natural connectivity exists (density 0.030); (5) cross-sectoral platforms exploiting Information and Communications specialization (38.42% in R&D) for manufacturing modernization.

Implementation should follow phased approach: strengthen commercial relationships, develop financing mechanisms, create shared infrastructure, establish cross-sectoral platforms. Success metrics should focus on network connectivity and financing fragmentation reduction rather than traditional R&D indicators alone.

7.3 Support Organization Implications

Professional associations (centrality 0.4095) can increase impact through sectoral specialization rather than broad representation, serving as knowledge brokers within sectors while facilitating cross-sectoral connections.

Universities and laboratories (centralities 0.2387, 0.2174) should develop commercial-oriented research programs aligning with market-driven logic, positioning as specialized service providers within commercial networks rather than competing with commercial actors.

Support organizations should prioritize shared testing infrastructure development serving multiple companies within commercial clusters, and design programs around objective-specific networks recognizing that R&D, financing, and testing require different relationship architectures. The six identified communities suggest opportunities to facilitate inter-cluster connections while respecting functional specializations.

Data Availability Statement

The data supporting the conclusions of this article are publicly available through CONACYT's official web portal. The Encuesta de Innovación Empresarial del Paraguay (EIEP) 2018-2020 dataset can be accessed from the science, technology and innovation indicators section at <https://www.conacyt.gov.py/indicadores-cti>. No additional permissions are required to access these data.

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