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Business resilience in the Quindío agro-industrial cluster: a forward-looking approach based on business networks

Resiliencia empresarial en el clúster agroindustrial del Quindío: un enfoque prospectivo basado en redes empresariales

Resiliência empresarial no cluster agroindustrial de Quindío: uma abordagem prospectiva baseada em redes empresariais

Adriana María Flórez Laiseca; Elkin Argiro Muñoz Arroyave

Master's degree in environment and sustainable development from the Universidad de Manizales, director and research professor of the Economics program at the Universidad del Quindío. ORCID: 0000-0003-1439-1236. E-mail: amflorez@uniquindio.edu.co, Armenia - Colombia.

Doctor in territorial studies from the Universidad de Caldas. Professor at the School of Regional Urban Planning of the Universidad Nacional de Colombia - Medellin. ORCID: 0000-0003-1667-5849. E-mail: elmunoza@unal.edu.co. Medellín - Colombia.

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Abstract

Introduction: This study examines the resilience of the Quindío agroindustrial cluster in the face of economic shocks, analyzing how integration and collaboration between firms, influence its adaptive capacity. **Objective**: To evaluate the impact of business networks on the resilience of the cluster, considering different levels of integration and their effect on the absorption of economic shocks and the diffusion of ideas. **Methodology**: A qualitative approach was used, complemented with business network simulations to model low and high integration scenarios. **Results**: Higher integration among cluster firms significantly strengthens their resilience to market shocks and facilitates access to knowledge and innovation. In addition, the importance of strengthening inter-firm linkages and R&D activities to enhance the competitiveness of the sector is highlighted. **Conclusions**: It was found that, at different levels of integration, networks influence the cluster's capacity to absorb shocks and disseminate innovations, determining aspects to guarantee sustainability and competitiveness in the long term. This provides empirical evidence on clusters and highlights the need to strengthen business networks, in addition to offering guidelines for the design and formulation of territorial planning policies and instruments.

Keywords: agribusiness; business cooperation; scientific innovation; qualitative methods; economic shocks; foresight; resilience.
JEL: C45; M21; O13; O33; L23; Q13.

Resumen

Introducción: Este estudio examina la resiliencia del clúster agroindustrial del Quindío frente a los choques económicos, analizando cómo la integración y la colaboración entre empresas, influyen en su capacidad de adaptación. **Objetivo**: Evaluar el impacto de las redes empresariales en la resiliencia del clúster, considerando diferentes niveles de integración y su efecto en la absorción de choques económicos y la difusión de ideas. **Metodología**: Se utilizó un enfoque cualitativo, complementado con simulaciones de redes empresariales para modelar escenarios de baja y alta integración. **Resultados**: Una mayor integración entre las empresas del clúster, fortalece significativamente su resiliencia ante las perturbaciones del mercado y facilita el acceso al conocimiento y la innovación. Además, se destaca la importancia de fortalecer los vínculos interempresariales y las actividades de I+D para potenciar la competitividad del sector. **Conclusiones**: Se encontró que, a distintos niveles de integración, las redes influyen en la capacidad del clúster para absorber los choques y difundir innovaciones, aspectos determinantes para garantizar la sostenibilidad y competitividad en el largo plazo. Lo anterior, aporta evidencia empírica sobre los clústeres y destaca la necesidad de fortalecer las redes empresariales, además de ofrecer orientaciones para el diseño y formulación de políticas e instrumentos de planificación territorial.

Palabras clave: agroindustria; cooperación empresarial; innovación científica; métodos cualitativos; perturbaciones económicas; prospectiva; resiliencia.

JEL: C45; M21; O13; O33; L23; Q13.

Resumo

Introdução: Este estudo examina a resiliência do cluster agroindustrial de Quindío diante de choques econômicos, analisando como a integração e a colaboração entre as empresas influenciam sua capacidade de adaptação. **Objetivo:** avaliar o impacto das redes de negócios sobre a resiliência do grupo, considerando diferentes níveis de integração e seu efeito sobre a absorção de choques econômicos e a difusão de ideias. **Metodologia:** foi utilizada uma abordagem qualitativa, complementada com simulações de redes de negócios para modelar cenários de baixa e alta integração. **Resultados:** A maior integração entre as empresas do cluster fortalece significativamente sua resistência a choques de mercado e facilita o acesso ao conhecimento e à inovação. Além disso, destaca a importância de fortalecer os vínculos entre as empresas e as atividades de P&D para aumentar a competitividade do setor. **Conclusões:**

Constatou-se que, em diferentes níveis de integração, as redes influenciam a capacidade do cluster de absorver choques e difundir inovações, que são aspectos determinantes para garantir a sustentabilidade e a competitividade de longo prazo. Isso fornece evidências empíricas sobre clusters e destaca a necessidade de fortalecer as redes de negócios, além de oferecer diretrizes para o projeto e a formulação de políticas e instrumentos de planejamento territorial.

Palavras-chave: agronegócio; cooperação empresarial; inovação científica; métodos qualitativos; choques econômicos; previsão; resiliência.

JEL: C45; M21; O13; O33; L23; Q13.

Introduction

In a globalized and highly competitive environment, companies face constant challenges to maintain their sustainability and growth. This challenge is particularly evident in sectors such as agribusiness, which involves the management, preservation, and industrial processing of raw materials derived from agriculture, livestock, forestry, and fisheries (Corella, 1993, p. 87), where integration and business collaboration become key elements for enhancing competitiveness and resilience. It is important to highlight that this sector represents a significant opportunity for economic growth in developing countries and for territorial development, especially considering 21st-century consumption trends (Organización de las Naciones Unidas para la Alimentación y la Agricultura [FAO], 2017).

In this context, business clusters have emerged as an effective strategy that enables companies to reduce costs, consolidate demand, and increase revenues through collaboration and the exploitation of synergies (Zadorozhna, 2014). This article presents a prospective analysis of the companies belonging to the Agro-industrial Cluster Initiative of Quindío under different scenarios of economic disruptions, focusing on how business integration and cooperation can influence their capacity for adaptation and recovery. This approach underscores the importance of studying business networks as drivers of growth and entrepreneurial success, as they create or strengthen a conducive environment for the performance of a company's internal resources, thereby ensuring long-term sustainability for both the firm and its entire value chain—from suppliers to end consumers. Accordingly, the

objectives of this study are threefold: (i) to identify the changing dynamics that influence the evolution of the agro-industrial cluster in Quindío; (ii) to assess how associations among companies within the cluster affect the absorption of economic shocks and the diffusion of ideas; and (iii) to propose recommendations to enhance integration and collaboration among cluster firms in order to strengthen their recovery capacity in the face of economic disruptions and improve their competitiveness. To achieve these objectives, the study employed a qualitative environmental analysis methodology, complemented by business network simulations to represent different levels of cluster development. This research emphasizes the importance of clusters as tools for regional and business economic development.

Following a review of previous studies on the importance of business networks and associative strategies in enhancing corporate competitiveness, the theoretical framework is established to define the core elements and theories underpinning this research. Consequently, it is essential to understand the concept of business networks, which are fundamentally based on associativity—defined as cooperation among members to achieve common benefits.

Indeed, in economic and business theory, the concept of a business network holds significant relevance due to its impact on organizational growth and the broader economy. In this regard, Galán et al. (2010) propose an analysis of business networks at a micro-level to reduce the complexity of such studies. Their research develops a typology of networks and sub-networks that facilitates the understanding of interorganizational relationships.

Along these lines, Urrutia y Cuevas (2016, p. 425) assert that associativity in business "is a means that facilitates coping with uncertainty in constantly changing and unstable environments through the creation and development of strategies that enable them to compete on equal terms." Such collaboration not only strengthens competitiveness but also enables firms to confront challenges such as economic shocks or other disruptions that may affect business performance.

According to Galán et al. (2010), business networks serve not only as support systems but also leverage the heterogeneity of their members to generate new competitive advantages. These authors argue that "the pursuit of benefits within networks or business collectives is essential for smaller organizations, as it allows them to compete globally against seemingly more powerful rivals" (p. 28). In this sense, business networks facilitate access to knowledge, market expansion, and the transfer of information and technologies—key elements for

competing in dynamic and globalized environments.

Within this same context, Becerra (2008) states that "networks are a way of organizing relationships among companies which, while continuing to compete, incorporate cooperation as part of their business strategy in order to achieve better performance in a given industry."

Innovation within business networks and clusters is not a linear process; rather, it is an emergent phenomenon fueled by the interaction and diversity of their members (Powell et al., 1996). Geographic proximity and network density facilitate the circulation of ideas and tacit knowledge, which stimulates experimentation and the adoption of new technologies and practices (Maskell & Malmberg, 1999). Moreover, collaboration in research and development projects, along with informal information exchange, enables firms to overcome individual limitations in resources and capabilities, thereby accelerating innovation and improving responsiveness to market changes (Rosenberg, 1983).

Furthermore, the success and sustainability of business networks and clusters largely depend on governance mechanisms and the level of trust among participants (Grandori & Soda, 1995). Governance can take various forms, ranging from formal agreements and specific organizational structures to shared social and cultural norms, all of which foster cooperation and mitigate the risk of opportunistic behavior (Williamson, 1985). Trust, in turn, acts as a lubricant for interactions, reducing transaction costs and promoting long-term collaboration, thereby facilitating the creation of collective value (Nahapiet & Ghoshal, 1998).

Densely connected business networks tend to be more effective in disseminating information and knowledge. From the perspective of network theory, it is possible to map the flow of knowledge within a cluster, identifying barriers and opportunities for improving technology transfer and the adoption of innovative practices among firms (Sepúlveda, 2023). Additionally, these networks can be classified as horizontal or vertical. Horizontal networks involve collaboration among companies operating at the same level of the value chain, whereas vertical networks refer to relationships among companies at different levels, such as suppliers and distributors. This classification helps to better understand the various forms of interaction and cooperation within a cluster (Instituto Alemán de Desarrollo y Sostenibilidad [IDOS], 2019).

It is necessary to note that a business cluster is a geographic concentration of firms, suppliers, academic institutions, and government entities operating within the same productive sector and collaborating to improve their competitiveness and innovation (Porter, 1998). These clusters facilitate knowledge exchange, market access, and resource optimization, generating benefits not only for participating companies but also for the regional and national economy (Enright, 2003).

The physical proximity between companies that make up a cluster fosters collaboration and reduces logistical costs (Jankowska et al., 2017). This environment encourages cooperative relationships among different actors, even in competitive contexts. Thus, companies not only compete in the market but also collaborate in strategic areas such as innovation, technological development, and human talent training (Enright, 2003).

This type of relationship has been conceptualized as coopetition, that is, the coexistence of competition and cooperation among organizations sharing common interests. According to Enright (2003), this dynamic generates significant efficiencies by integrating producers, suppliers, and distributors, resulting in improvements both in production processes and marketing strategies (Porter, 1998).

The role of clusters as mechanisms for generating business networks is fundamental, since they promote associativity between different companies in the sector, with the objective of optimizing their collective performance without compromising their autonomy. In addition, because:

> They include not only companies but also institutions such as academic programs, trade associations and standard-setting organizations. In turn, they leverage the public goods of the community in which they are located, such as schools and universities, clean water, free competition laws, quality standards, and market transparency. (Porter & Kramer, 2011, p. 13)

Additionally, clusters are not static structures; they evolve over time. Network theory provides tools to analyze how relationships and structures within a cluster change, enabling an understanding of their adaptation to new market challenges and opportunities (Sepúlveda, 2023).

In the agro-industrial context, cluster formation facilitates collaboration among companies, research institutions, government entities, and other relevant actors, promoting innovation, technology transfer, and regional economic development. A notable example is the work of the Red Clúster Colombia, which focuses on strengthening the competitiveness of priority agricultural sectors through productive articulation initiatives. These initiatives enable the alignment and targeting of public policies oriented toward sectoral development with the objective of fostering business growth along agro-industrial value chains (Red Clúster Colombia [RCC], 2022).

A research and business development group conducted a prospective analysis of the plastics industrial sector in the city of Bogotá D.C. using the Delphi method for the construction of future scenarios for the year 2019. The objective of this study was to guide business decisions for the improvement of productivity and the understanding of the future behavior of the sector. The findings indicate that, for that year, the use of materials from renewable sources and natural raw materials was foreseen; however, 67% of the experts surveyed argue that, by 2019, the plastics cluster in Bogota, would not reach world-class performance with technological and industrial development in line with international standards. This was attributed to the lack of research supporting its growth and strengthening, as well as low investment and the absence of associations representing this type of initiatives (Guarín et al., 2013).

On the other hand, within comparative studies, Aguilar y Cruz (2015) analyzed the automotive cluster in San Luis Potosí, Bolivia, with the aim of describing and examining the cluster's production chain, its integration, and its level of consolidation. Using a qualitative methodology based on semi-structured interviews, they concluded that the cluster was in the initial phase of formation. They identified that both the production chain and the supporting institutions needed to be strengthened, since a solid production chain had not yet been established around the automotive industry.

In line with the above, Becerra y Serna (2012) analyzed the impact of links between local companies and institutions on the development of innovation and R&D in the city of Manizales, Colombia. To this end, they collected information from 246 companies that make up the city's textile cluster and used a logit model for empirical verification of the data. The results showed a low level of R&D activities in companies, and the model estimated that the existence of links between companies to develop R&D activities increases the probability of

generating innovation in the sector by 49%. As a main conclusion, the authors highlight that linked companies significantly strengthen R&D activities compared to those that operate in isolation. They also emphasize that this linkage has a direct impact on the competitiveness of the sector.

Finally, in 2018, an article entitled “Analysis of the most representative aerospace clusters worldwide and their impact on the development of the Valle del Cauca Aerospace Cluster” was published. This study provided an overview of aerospace clusters worldwide, taking as a reference the most representative ones in Europe, Canada, the United States, and Latin America, where competitive strategies applicable to the development of the sector in Valle del Cauca were identified. Through information analysis and synthesis techniques, it was found that the exchange of cluster policies with Europe and the adoption of innovative models with the United States can strengthen this industry. Mexico was also identified as a regional leader in technological development, with sustained growth over the last eight years. The findings showed that the analysis of international clusters facilitates the exchange of information, innovation, and technology that contribute to improving the sector, competitiveness, and economy of a country (Morante y López, 2018).

This is crucial to understanding the factors that influence a company's success. According to Porter y Kramer (2011), “social needs, and not just conventional economic needs, are what define markets. It also recognizes that the ills or weaknesses of society often create internal costs for companies” (p. 4). This implies that, for organizations, it is not enough to create a favorable environment internally; it is also necessary to forge networks in their external environment to ensure optimal performance.

Methodology

Network theory allows us to detect and analyze the ways in which companies within a cluster connect and collaborate. By representing organizations as nodes and their relationships as links, it is possible to visualize the structure of the cluster and assess the degree of cohesion of its components (Fortunato, 2009). This representation facilitates the identification of subgroups or communities that cooperate closely, as well as the analysis of the impact of these interactions on efficiency, information dissemination, and innovation.

Furthermore, through the use of metrics such as centrality, network theory allows us to identify strategic actors who act as key intermediaries in the circulation of resources, knowledge, and innovative practices. These companies occupy privileged positions within the network and play a fundamental role in the development, strengthening, and sustainability of the cluster (Serrano & Boguñá, 2006).

Based on these theoretical foundations, this study developed a qualitative analysis of the environment (Ochoa, 2013), supported by results obtained through focus groups and semi-structured surveys applied to 45 companies in the department of Quindío (Colombia) during the years 2019, 2020, and 2021. The organizations analyzed belong to the agro-industrial cluster, in the food category, and are engaged in the processing of products in different lines: horticulture and aromatics, confectionery, honey, panela and cocoa, baking, biscuits and flour, dairy and meat products, spirits and beverages, as well as plantain and banana snacks.

To complement the qualitative analysis, a network simulation model was implemented that represented companies as nodes and their production chains as links between them or as relevant common factors. Each link was assigned a random value between 0 and 1 to represent the intensity of the commercial relationship. The model configured two contrasting scenarios: a Low Evolution Cluster (CBE) and a High Evolution Cluster (CAE), with the purpose of exploring the impact of different levels of integration and collaboration. The simulation worked with randomly generated data, focusing on key variables such as the diffusion of ideas, economic shocks, technology adoption, and business interactions, expressed by the intensity of the relationships between nodes.

Four validation scenarios were also designed to examine the dynamic behavior of the network:

- Dissemination of ideas: in this scenario, each company accesses specific information that it can retain and share with other connected organizations. The information acquired is not lost; once incorporated, it is maintained and transmitted throughout the network.

- Economic shocks or disruptions: the impact of adverse events on companies is simulated, the effect of which spreads due to the interconnection between nodes. This scenario highlights the importance of collective and coordinated action to address the duration of the crisis and promote organizational learning that mitigates or reduces future impacts.

- Technology adoption: this scenario analyzes how organizations adopt technologies, retain them, share them, or eventually abandon them if their neighboring companies do not incorporate them. This reflects dynamics of pressure or influence within the network.

- Business interactions: this scenario simulates the evolution of commercial and value chain relationships between companies in the cluster, showing how these are strengthened or weakened depending on the degree of integration. Interactions generate differentiated impacts that affect collective performance.

The results were validated through graphical analysis of the networks generated after the simulation. It was observed that the higher the level of linkage within the cluster, the greater the density of the network, suggesting an increase in connectivity and collaborative relationships between companies. Data management was carried out using pseudo-random numbers generated in Excel, which were subsequently incorporated into the ORA-LITE simulation software developed by the Center for Computational Analysis of Social and Organizational Systems (CASOS) at Carnegie Mellon University. This software allowed the three scenarios described above to be implemented through specific subprocesses available for dynamic network modeling.

Given that clusters are identified as collaborative networks between companies that facilitate cost reduction and demand consolidation, which in turn boosts revenue, companies act as nodes within the cluster, while interactions between them express the connections between these nodes. This structure can be visualized through graphs or networks, which

provide a clear representation of the dynamics operating in the economic environment. In order to simulate the cluster, chains of nodes are generated according to the level of evolution of the cluster, and to represent the level of evolution, two levels are defined: low and high chaining.

The low-level cluster, or low chaining, is characterized by many of its relationships being underdeveloped, resulting in a low level of associativity between companies, represented by the fact that only 15% of possible associations are present. In contrast, the high-level cluster has developed 75% of the possible associations between the companies that comprise it. In network simulation, the propagation of events is configured as a phenomenon that spreads across the network. There are four ways to consider this in networks: diffusion of ideas, negative or positive economic shocks, and technology adoption.

Results

Dissemination of ideas

Each organization has access to information, which it can retain and share with other nodes. The information received is not lost. If a company receives information, it keeps it over time and shares it with the attached nodes.

Negative or positive economic shocks

Economic shocks or disturbances affect the entire business organization, and because they are interconnected with other structures in the productive environment, the impact tends to spread. In this sense, it is essential to promote joint action to address the duration of the crisis and encourage collective learning to prevent recurrence or minimize its recurrence in the future.

Technology adoption

Technology adoption demonstrates the process by which organizations adopt new technologies, retain them based on their usefulness, share them with other companies within the cluster, and in some cases abandon them if they perceive that their neighboring companies

do not embrace them. This behavior demonstrates the influence it exerts on technological decision-making, while also reflecting situations of pressure and collective adaptation within the network, affecting the speed and scope of technological or scientific innovation processes.

Cluster configuration

The total number of companies in the cluster was defined as 45; relationships with random values were generated for these companies to represent these clusters. To configure the low-evolution network, it was decided to activate relationships with a value greater than 0.85, which means that only 15% of all linkages are considered valid.

For a high-evolution cluster, relationships representing 75% of the chains were defined for the 45 companies, selecting those with a value greater than 0.25.

Definition of simulation parameters

In each network representing a cluster, an event was simulated to analyze how companies respond according to the cluster's level of evolution. The simulation parameters include a three-year time horizon. In addition, the resistance of each node to the event is set at 0.25 for the highly evolved cluster and 0.75 for the lowly evolved cluster, reflecting the ability of companies to integrate the value chains derived from their membership in the cluster. These values indicate that, if companies are in a low-evolution cluster, they have not developed efficient mechanisms for collaborating with value chains, while in a high-evolution cluster, companies have developed mechanisms for collaborating and generating added value, making the transmission of effects faster.

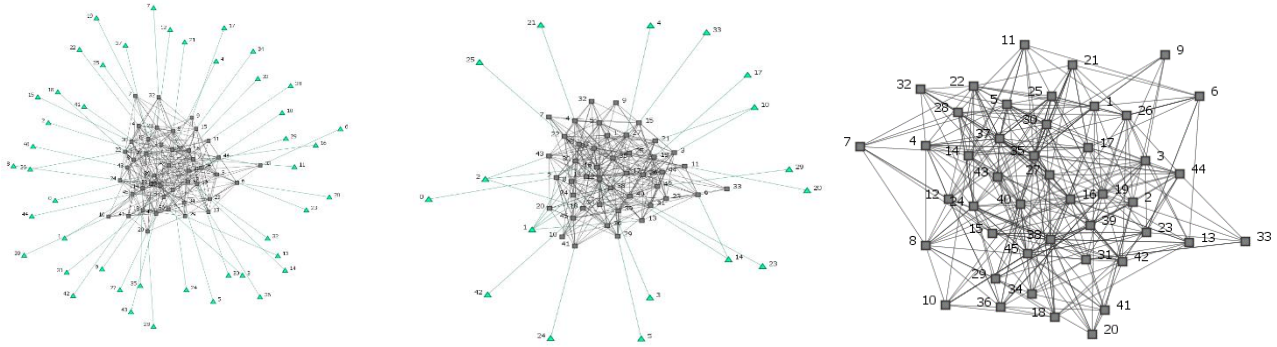
Prospective pandemic simulation

Economic shock in a low-evolution cluster

A negative or positive economic shock was simulated on the network for three periods, corresponding to the three-year window of the study. The level of immunization of the organizations was set at zero, meaning that all are exposed to contagion. The impact of the economic shock lasts for one year. The green triangles indicate the order of organizations affected by the event. The results for the first year are shown in Figure 1.

Figure 1

Simulation of an economic shock (low evolution cluster)



First year. CBE | Second year. CBE | Third year. CBE

Source: Own elaboration.

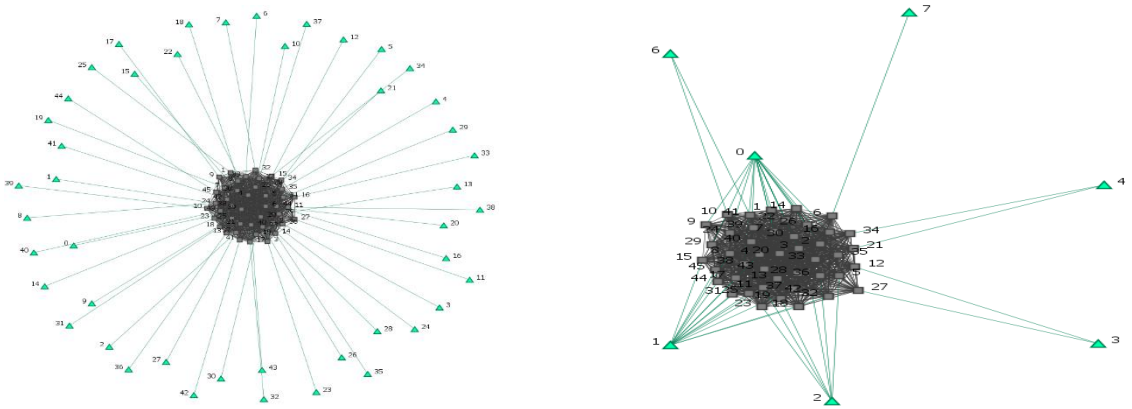
Although the chains are low evolution, most companies suffer the effects of the shock, whether positive or negative. At the end of the first period, companies have suffered the economic impact. For the second period, the companies that were infected last are the ones that continue to experience the effects of the event, which in this case are 17. By the third year, the economic shock has completely dissipated.

High-evolution cluster economic shock (CAE)

Under the defined parameters, the effect of an economic shock was simulated (Figure 2), with a level of immunity to contagion of 0.25, which exposes organizations to a faster and more integrated spread of the impact. The maximum contagion period was set at one year. Considering that the cluster network is highly dense due to the significant number of relationships developed between companies, the spread of both positive and negative shocks occurs more rapidly in this scenario.

Figure 2

Simulation of an economic shock (High Evolution Cluster)



First year. CAE Second year. CAE

Source: Own elaboration.

In the second year, seven companies are affected, a figure well below the 17 companies in the CBE. These figures show that the CAE quickly absorbs the effects of an economic shock, both positive and negative. Greater absorption means that, as a whole, companies would be better prepared to deal with it.

Simulation of the dissemination of ideas

The dynamics of this type of dissemination begin when a company generates an idea and decides to share it with the rest of the companies in the cluster. Once the idea is transmitted, it is not lost in the process, but remains active and available in the system, circulating to all other organizations within the network (Figure 3). This ensures that any company can access the information at any time, while also facilitating the collective appropriation of knowledge and innovative processes.

Figure 3

Simulation of the dissemination of ideas (Low Evolution Cluster)

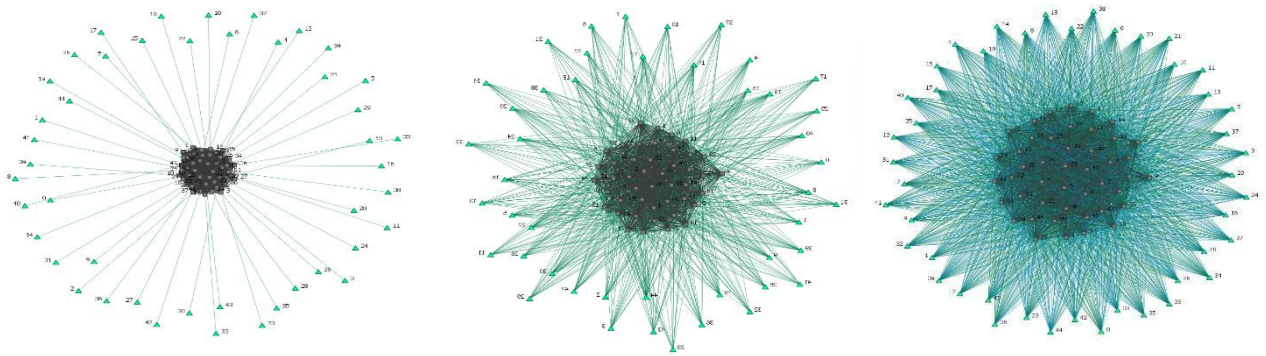
First year. CBE | Second year. CBE | Third year. CBE

Source: Own elaboration.

Initially, sharing an idea is positive in the sense that its dissemination can resonate with other companies in the cluster. In the second year, dissemination begins to intensify, increasing the density of the network as more organizations join the knowledge exchange. By the third year, the dissemination process is consolidated, indicating that the idea has circulated effectively throughout the business network (Figure 4).

Figure 4

Simulation of the dissemination of ideas (*High Evolution Cluster*)



First year. CBE | Second year. CBE | Third year. CBE

Source: Own elaboration.

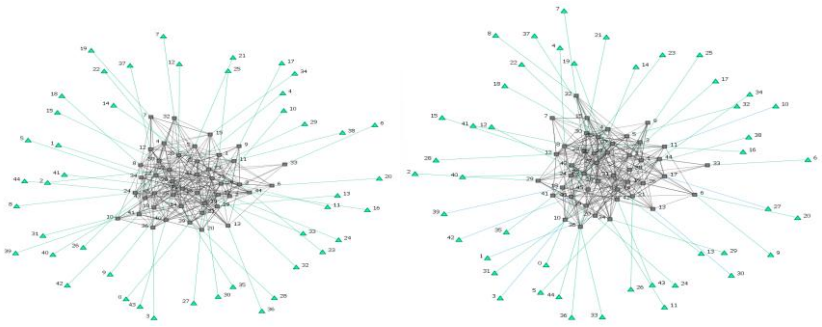
The initial phase of idea diffusion is similar to the previous one. The difference lies in time: the second year generates a much denser network, indicating that idea diffusion expands to a larger number of companies given the characteristics of the cluster. In the third year, idea diffusion achieves a density where companies share their ideas with the rest of the cluster.

Simulation of business interactions

Another similar event corresponds to business interactions in the network. This considers that the integration of the value chain in the cluster manages to generate synergies between companies, simulating their evolution, as can be seen in Figure 5.

Figure 5

Simulation of Business Interactions (Low Evolution Cluster)

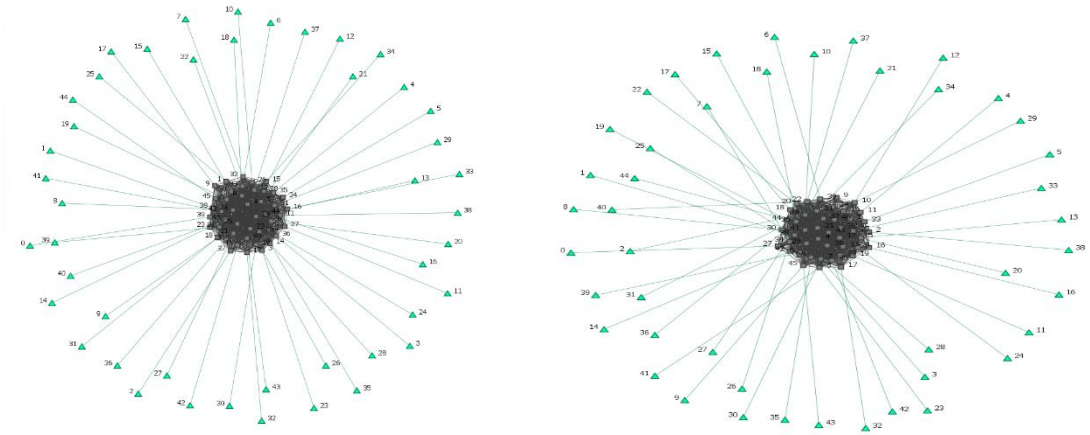


Source: Own elaboration.

For highly evolved cluster networks, it can be seen that business interaction remains over time. The CBE generates business within itself, proportional to the configuration of its relationships (Figure 6).

Figure 6

Simulation of Business Interactions (High Evolution Cluster)



First year. CAE Second year. CAE

Source: Own elaboration.

The CAE generates business between organizations in a more stable manner over time, meaning that the benefits generated from internal synergies are greater compared to the CBE.

Discussion

The results obtained through the simulation of networks in the agroindustrial cluster of Quindío reveal significant findings on the dynamics of business networks and their impact on the resilience and development of the sector. First, the simulation of economic shocks or disturbances, both positive and negative, showed that clusters with high evolution, characterized by greater integration among firms, exhibit a greater capacity to absorb and recover from disturbances. This resilience is attributed to the efficient diffusion of information and resources, facilitated by network integration, which is consistent with the postulates of network theory (Sepúlveda, 2023) and suggests a key recommendation for public policy: the implementation of initiatives that actively promote collaboration and connectivity among

cluster firms, thus strengthening their capacity to adapt and mitigate risks in the face of economic shocks.

The complexity and adaptive systems perspective offers a valuable lens for understanding the dynamic evolution of business networks and clusters (Holland, 1995). These structures are not static entities, but complex systems that continuously self-organize and adapt to changing environmental conditions. Interactions between agents, feedback and the emergence of properties are key elements in understanding how clusters transform, face challenges and take advantage of new opportunities over time (Stacey, 1996).

Network simulation indicates that greater integration enhances the benefits of clustering. In this sense, it was observed that the highly evolved cluster shares a higher level of knowledge. The results suggest that, when companies are more integrated, more organizations become contagious more quickly; however, since the initial contagion is greater, the cluster can emerge from the crisis in a shorter time. This is positive because organizations experience the effects more quickly, allowing them to adapt more quickly to business realities. Overall, they can overcome the effects of the negative shock in a shorter time. These findings are consistent with Sepúlveda (2023), who argues that cluster cohesion refers to the strength of ties among its members. A network analysis makes it easier to evaluate the density of connections and the possible existence of bottlenecks or points of failure that compromise the stability of the cluster. Understanding the robustness of the network is crucial for designing strategies to strengthen inter-enterprise relationships and mitigate risks.

This is evident in the second year, when only six organizations perceive the effects of the shock, in contrast to the low evolution cluster, where ten organizations experience the effects of the event in the same period. Economic shocks spread aggressively in the network, so that, by the first year, most organizations have experienced their effects. By the second year, only the remnants or those affected late remain. By the third year, all organizations have overcome the impact of the event. In contrast, low-evolution clusters, with less developed relationships, show greater vulnerability and slower recovery. This underscores the importance of strengthening inter-firm linkages to increase the resilience of the agribusiness sector.

Second, the simulation of idea diffusion showed that cluster integration plays a crucial role in the circulation of knowledge. In highly evolving clusters, ideas diffuse faster and extensively, reaching a larger number of firms in a shorter time. This result is consistent with

the cluster and business network literature, which emphasizes the importance of proximity and collaboration for knowledge sharing and innovation (Enright, 2003; Porter, 1998). The ability to share ideas and knowledge efficiently not only strengthens the competitiveness of individual firms, but also boosts the development of the cluster as a whole. For example, a study on the nanotechnology cluster in Nuevo León used the ARS to analyze the collaborative relationships between organizations and their impact on the creation of science, technology and innovation. (Sepúlveda, 2023)

In addition, the simulation of business interactions revealed that highly evolving clusters generate more stable and beneficial synergies for companies. The integration of the value chain and collaboration between companies allow optimizing processes, reducing costs and increasing efficiency, resulting in greater competitiveness and sustainability (Zadorozhna, 2014). On the contrary, clusters with low evolution, present less interaction between companies, which limits the generation of synergies and affects their performance. To take advantage of their potential, it is essential to design and implement public policies that strengthen the cluster value chain. This implies facilitating the coordination of suppliers, producers and distributors, encouraging the adoption of Information and Communication Technologies (ICT), promoting the development of quality standards and fostering internationalization.

In conclusion, the results of this study support the importance of business networks and collaboration for the development and resilience of the Quindío agroindustrial cluster. The high evolution of the cluster, characterized by greater integration, facilitates the absorption of economic shocks, the dissemination of ideas and the generation of synergies, which boosts the competitiveness and growth of the sector. According to the Economic Commission for Latin America and the Caribbean (ECLAC), clusters and business networks are spaces where companies and institutions, with a certain geographical or sectoral proximity, interact to improve their performance. To this end, it is essential to develop shared strategic agendas that intensify interaction and deepen mutual trust (CEPAL, 2023). These findings have important implications for regional development policies, which should promote the creation and strengthening of business networks as a key strategy for the economic development and sustainability of the agroindustrial sector.

Conclusions

The findings derived from the empirical resea rch confirm the theoretical premise that conceives network integration as a determinant of cluster resilience. This conclusion is aligned with the postulates of network theory, which emphasizes the importance of interconnections between actors for the efficient flow of information, resources and capabilities. In this sense, the density and structure of business networks emerge as elements that shape the cluster's ability to adapt and respond effectively to environmental disruptions.

From a theoretical perspective, this study strengthens the existing body of knowledge in the field of clusters and business networks by providing empirical evidence that quantifies and qualifies the relationship between network structure and organizational resilience. In particular, the relevance of key concepts such as “competition” (Enright, 2003) and the “strength of weak ties” (Granovetter, 1973) for understanding the dynamics of collaboration and competition underlying cluster resilience is corroborated. Also, the relevance of resource dependence theory to analyze how networks facilitate access to critical resources and uncertainty mitigation is evidenced.

At the practical level, the research results strongly suggest the need for regional development policies to adopt a strategic approach focused on the active promotion of collaboration and the creation of strong and cohesive business networks. This orientation calls for the implementation of interventions that promote inter-organizational trust, the fluid exchange of knowledge and the coordinated execution of joint innovation and development initiatives. In this context, the fundamental role of support institutions (development agencies, chambers of commerce, universities, among others) is highlighted as catalysts for the formation and strengthening of these networks, providing meeting platforms, intermediation services and specialized training programs.

Indeed, this study underscores the critical importance of business networks as intangible infrastructures that underpin the resilience and competitiveness of agroindustrial clusters in the face of economic shocks. It is hoped that the findings and reflections presented here will help inform the formulation of public policies and business strategies that promote sustainable development and economic prosperity in the regions, promoting synergies between

academia, the public and business sectors, so as to contribute to the consolidation and strengthening of lines of research applied to the analysis of the business fabric, especially its level of integration and associativity as a determining factor for competitiveness and regional development.

It is important to mention that, within the limitations of the study, the methodology could be complemented. It is proposed for future research the incorporation of quantitative and mixed methods that allow a more complete triangulation of the results. Likewise, it is necessary to analyze in depth the resilience not only of the clusters, but of the business fabric in different economic sectors, such as tourism, agriculture, commerce, construction, among others, to establish comparisons of integration relationships, levels of technologies, transfer of knowledge and ideas and business interaction, in order to evaluate their capacity to respond to crises and thus generate business strategies or public policies that strengthen their resilience.

Finally, promote scenarios for discussion and evaluation of the role played by support institutions such as the National Learning Service (SENA), the Chamber of Commerce, the Regional Commission for Competitiveness and Innovation, the Inter-Gremial and Business Committee, development agencies, business incubators, universities and trade associations, in the consolidation of networks that promote associativity and forward-looking strategies to face market challenges and economic crises. This requires the articulation of these institutions for the evaluation of public policies aimed at guaranteeing efficient associativity and permanent innovation.

Ethical considerations

This qualitative research took into account ethical considerations based on relationships of trust and reciprocity, with a commitment to cause no harm, for which it received the endorsement of the Ethics and Bioethics Committee of the University of Quindío. Informed consent was obtained collectively at the time of conducting the research for the processing of data.

Conflict of interest

All authors made significant contributions to the document and declare that there is no conflict of interest related to this article.

Declaration of authors' contribution

Adriana María Flórez Laiseca: Conceptualization, methodology, research, formal analysis, project management, fundraising, supervision.

Elkin Argiro Muñoz Arroyave: Validation, software, methodology, formal analysis, research, writing: drafting and revision.

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