

Determinants of innovation in aquaculture organisations of the Peruvian Amazon

*Determinantes de inovação em organizações aquícolas da
Amazônia Peruana*

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ABSTRACT

Amazonian aquaculture is recognised as a strategic sector for food security, employment generation, and ecosystem conservation, particularly in a context where innovation is essential to addressing environmental and social challenges. This study aimed to analyse the main determinants of innovation in aquaculture organisations in the San Martín region of Peru. A cross-sectional quantitative design was employed, using face-to-face surveys administered to a random sample of 76 organisations benefiting from the National Programme for Innovation in Fisheries and Aquaculture. Data were analysed using partial least squares structural equation modelling (PLS-SEM) to assess the reliability and validity of the measurement model and the structural relationships between seven internal and external determinants and three types of innovation: process, organisational, and marketing. The results indicate that technological cooperation and fiscal incentives positively influence innovation, highlighting the importance of public policies and collaborative networks in supporting a competitive and resilient aquaculture sector.

Keywords: Aquaculture. Innovation determinants. Technological cooperation.

RESUMO

A aquícultura amazônica é reconhecida como um setor estratégico para a segurança alimentar, a geração de emprego e a conservação de ecossistemas, em um contexto no qual a inovação é fundamental para responder a desafios ambientais e sociais. O objetivo desta pesquisa foi analisar os principais determinantes da inovação em organizações aquícolas na região de San Martín, no Peru. Foi adotado um desenho quantitativo transversal, por meio de entrevistas presenciais aplicadas a uma amostra aleatória de 76 organizações beneficiárias do Programa Nacional de Inovação em Pesca e Aquícultura. A análise foi realizada com modelos de equações estruturais com mínimos

quadrados parciais, avaliando a confiabilidade, a validade e as relações estruturais entre sete determinantes internos e externos e três tipos de inovação (processos, organizacional e marketing). Os resultados evidenciam que a cooperação tecnológica e os incentivos fiscais influenciam positivamente a inovação, destacando a importância de políticas públicas e de redes colaborativas para um desenvolvimento aquícola competitivo e resiliente.

Palabras clave: Acuicultura. Determinantes de innovación. Cooperación tecnológica.

1 INTRODUCTION

Aquaculture has established itself over recent decades as the fastest-growing food production sector worldwide, playing a strategic role in contemporary agri-food systems, particularly in emerging economies, where it contributes to food security and job creation (Bohnes *et al.*, 2022; FAO, 2022). Since the early 2000s, while capture fisheries have remained stable, aquaculture has grown steadily, becoming a productive alternative to the stagnation of fishery resources and a factor that may help reduce pressure on wild populations (Naylor *et al.*, 2021).

Within this framework, aquaculture is directly linked to the Sustainable Development Goals (SDGs) of the 2030 Agenda. Its importance lies not only in the supply of nutritious food but also in its contribution to job creation, economic development, and the cultural preservation of numerous communities (FAO, 2022; Troell *et al.*, 2023). Aquatic products—both farmed and captured—are fundamental to food security: in 2020, global per capita consumption reached 20.2 kg, compared to 9 kg in 1961, providing about 17% of the world’s animal protein intake and accounting for nearly 20% of the protein diet of 3.3 billion people (FAO, 2022).

Meeting the 2030 Agenda will require partnerships, innovation, and comprehensive strategies at multiple scales (Troell *et al.*, 2023). In this sense, aquaculture not only represents a source of animal protein with a lower environmental footprint than traditional livestock farming (Bennett *et al.*, 2021; Costello *et al.*, 2020; Springmann *et al.*, 2018) but also constitutes a sector capable of adapting to sustainability demands in food production (Bohnes *et al.*, 2022).

In Peru, aquaculture accounts for only 2.2% of national hydrobiological production, despite the favourable natural conditions offered by the coast, highlands, and Amazon region (FAO, 2022; Hidalgo, 2019). Nevertheless, since 2015, the activity has shown sustained growth, reflected in the increasing number of licences granted, the rise in gross production value, and its contribution to job creation (Produce, 2024). Looking ahead, it is projected that by 2030, fishery production will decrease by 23%, while aquaculture will grow by 32% compared to 2018. However, a significant gap in the supply of hydrobiological products will persist (FAO, 2022).

Given this potential, the Peruvian government has implemented regulatory frameworks and support instruments, such as the General Aquaculture Law (2016) and the National Programme for Innovation in Fisheries and Aquaculture – PNIPA (2017–2023), which co-financed more than 1,500 projects with an investment exceeding 427 million soles (PNIPA, 2023). However, structural limitations remain, particularly the weakness of the innovation services market, the lack of coordination between technological supply and demand, and low competitiveness relative to regional countries such as Chile and Brazil (Produce, 2023).

The Amazon is a particularly relevant case, as it harbours one of the world’s greatest diversities of freshwater fish. However, only about 280 species are used for human consumption, many of which are under conservation threat (Albert *et al.*, 2011; Dagosta; Pinna, 2019; Pelicice *et al.*, 2021). In this context, Amazonian aquaculture—particularly the cultivation of native species—emerges as a sustainable alternative, with a carbon footprint up to ten times lower than livestock farming per tonne of protein produced, and without requiring further agricultural expansion (Pacheco *et al.*, 2025).

Nevertheless, the sustainability of aquaculture depends largely on the social and institutional dynamics that mediate innovation processes (Ferreiro; Sousa, 2019). These processes may originate from science, local knowledge, or the private sector, and develop in diverse economic and political environments (Alexander *et al.*, 2015; Jespersen *et al.*, 2014). Therefore, understanding the multifaceted nature of aquaculture, which integrates environmental, social, and economic dimensions, is essential to identify both the opportunities and challenges that will shape its future development (Troell *et al.*, 2023).

1.1 DETERMINANTS OF INNOVATION

In today's business environment, characterised by uncertainty and rapid technological change, innovation has become a central element of organisational competitiveness and sustainability (Teece, 2007). Various authors have identified internal determinants (strategy, absorptive capacity, organisational structure, and culture) and external determinants (government support, technological cooperation, and market factors) that influence innovative outcomes (Amabile *et al.*, 2004; Crossan; Apaydin, 2010; Keizer *et al.*, 2002).

1.1.1 INTERNAL DETERMINANTS OF INNOVATION

The internal environment is crucial to the capacity for innovation of aquaculture organisations, as it provides the strategic and cultural foundations needed to translate resources into sustainable outcomes. Strategic orientation, in particular, ensures that decisions align with the institutional mission and vision, serving as a framework that guides and strengthens innovation processes (Valladares, 2012; Yam *et al.*, 2011). The literature highlights that a strategy explicitly linked to innovation enhances idea generation and facilitates the integration of new technologies and processes (Crossan; Apaydin, 2010; O'regan; Ghobadian, 2005). In addition, absorptive capacity is a key mechanism for transforming external knowledge into competitive advantages, integrating the processes of knowledge acquisition, assimilation, transformation, and exploitation (Todorova; Durisin, 2007; Zahra; George, 2002). Organisational culture also acts as a catalyst for innovation, encouraging openness to learning, risk-taking, and recognition of employee-initiated initiatives (Becheikh *et al.*, 2006). Furthermore, intrapreneurship constitutes another internal determinant, referring to the ability of members of an organisation to generate and promote new ideas, initiatives, or projects from within established structures, thereby contributing to innovation capacity (Antoncic; Hisrich, 2003; Gawke *et al.*, 2019). Finally, organisational structure affects the speed and quality of innovation processes, as lower levels of centralisation and formalisation facilitate knowledge flows and greater adaptability to change (Liu *et al.*, 2018).

1.1.2 EXTERNAL DETERMINANTS OF INNOVATION

External environmental determinants are key factors shaping organisations' capacity for innovation, arising from regulatory, technological, and market environments that extend beyond organisational boundaries. Firstly, government support is a decisive factor in the development of innovation, particularly through public policies and fiscal incentives. Bell and Pavitt (1993) highlight that the availability of funding for basic research, alongside grants, awards, and loans, is an essential instrument for stimulating the generation and dissemination of innovations. Moreover, Becheikh *et al.* (2006) note that these measures, together with regulations and public-private partnerships, have been crucial to the competitiveness of the most dynamic economies when compared with those with lower innovative capacity.

Another critical component of the external environment is technological cooperation, which reflects the increasing reliance of innovative organisations on external sources of knowledge. The open

innovation literature argues that firms cannot rely exclusively on internal resources, but must interact with universities, research institutes, suppliers, customers, competitors, and consultants, forming networks that enhance their capacity for innovation (Chesbrough, 2006). Models such as the Triple Helix (Etzkowitz; Leydesdorff, 2000) and the democratisation of innovation (VON HIPPEL, 2005) emphasise that the quality of these collaborative relationships determines the speed and success of innovation processes (Ferguson, 2005).

Finally, market orientation is another key external determinant, reflecting organisations' ability to collect, disseminate, and respond effectively to market changes, integrating customer feedback into the development of innovative products and services (Jaworski; Kohli, 1993; Slater; Narver, 1994). Organisations that systematise market learning can strengthen their competitiveness by transforming customer knowledge into innovations that add value (Simpson *et al.*, 2006; Valladares, 2012).

This research aims to analyse the influence of the main determinants of innovation, both internal and external, on aquaculture organisations engaged in fish production in the San Martín region. The study seeks to provide evidence from a strategic Amazonian territory, where biodiversity, social challenges, and the need for sustainable production converge, thereby contributing to a better understanding of the factors that shape the competitiveness and development of the aquaculture sector.

2 METHODOLOGY

The research focused on the analysis of aquaculture organisations engaged in fish production at the first stage of the value chain—namely, cultivation and grow-out—while excluding processing units and other entities. The reference population comprised organisations in the San Martín region that benefitted from the National Programme for Innovation in Fisheries and Aquaculture (PNIPA) between 2018 and 2023, during which 182 aquaculture innovation projects were funded. From this database, a random sample of 76 organisations was selected, representing a substantial proportion of the population. Data collection was carried out through face-to-face surveys administered at production centres; when producers could not be reached in person, virtual surveys were conducted. The surveys targeted project coordinators or legal representatives, as they were the individuals most familiar with innovation-related activities. Prior to administration, all participants were fully informed of the study's aims, ensuring confidentiality and the exclusive use of data for research purposes.

The instrument used was designed based on specialised literature and subjected to a two-phase validation process. In the first phase, a panel of experts evaluated the relevance and clarity of the items; in the second, a pilot field test was conducted, which enabled the refinement of certain items and, in particular, justified the exclusion of the product innovation dimension, as the surveyed organisations did not develop this type of innovation. Thus, the dependent variable was defined as the degree of innovation in three dimensions: process innovation, organisational innovation, and marketing innovation. The independent variables corresponded to the determinants of innovation, classified as internal factors (strategy, absorptive capacity, organisational structure, and organisational culture) and external factors (government support, technological cooperation, and market factors), as shown in Figure 1.

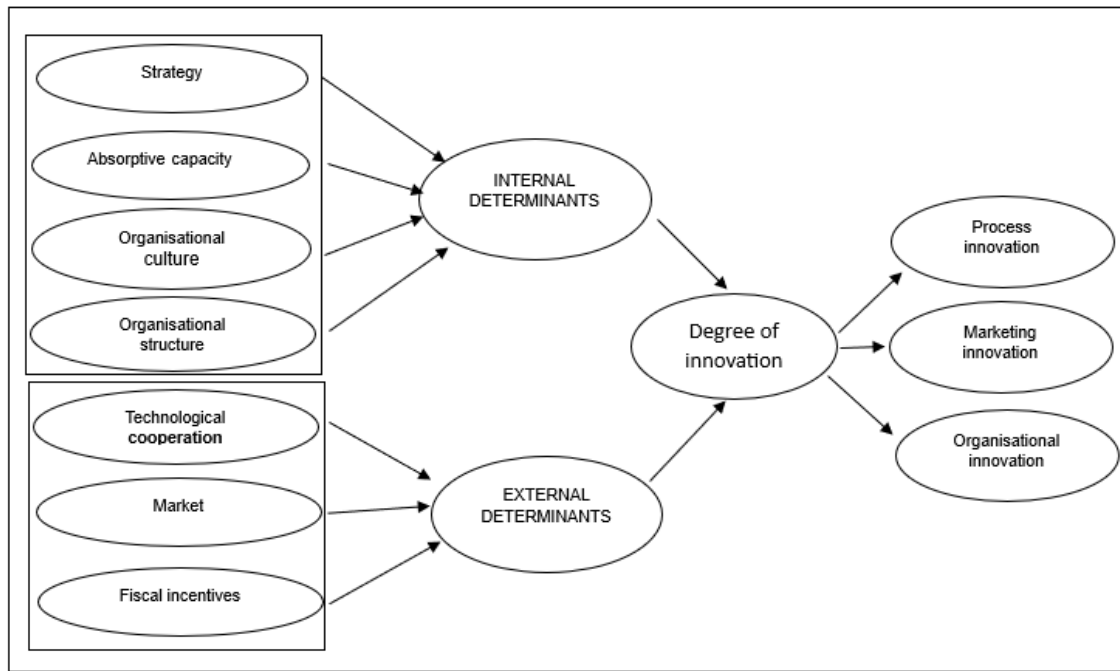


Figure 1 – Conceptual framework of the research.

Source: The authors.

Data analysis was conducted using partial least squares structural equation modelling (PLS-SEM), a technique suitable for moderate sample sizes and complex latent variable structures (Hair *et al.*, 2022; Henseler *et al.*, 2016). The procedure comprised estimating both the measurement and structural models, following standardised evaluation criteria. For the measurement model, internal consistency reliability was assessed using Cronbach’s alpha and composite reliability (≥ 0.70), convergent validity using the average variance extracted ($AVE \geq 0.50$), discriminant validity using the Fornell-Larcker criterion and the heterotrait-monotrait ratio ($HTMT \leq 0.85/0.90$), and collinearity using the variance inflation factor ($VIF < 3-5$) (Fornell; Larcker, 1981; Hair *et al.*, 2022). For the structural model, path coefficients were assessed using bootstrapping with 5,000 resamples and percentile and BCa confidence intervals. The coefficients of determination (R^2), effect sizes ($f^2 = 0.02/0.15/0.35$), and predictive relevance ($Q^2 > 0$) were also evaluated. As a global diagnostic, the SRMR index ($< 0.08/0.10$) was reported (Hair *et al.*, 2022).

3 RESULTS AND DISCUSSION

This section presents the multivariate results, beginning with the evaluation of the measurement model, followed by the analysis of the structural model. The influence of internal factors (strategy, absorptive capacity, organisational culture, and organisational structure) and external factors (market, technological cooperation, and fiscal incentives) on the different types of innovation (process, marketing, and organisational innovation) is considered.

Table 1 displays the coefficients for the validity and reliability parameters of the proposed general model. Most constructs exhibited values consistent with those recommended in the literature: average variance extracted (AVE) above 0.50, Cronbach’s alpha greater than 0.70, and composite reliability above 0.70 (Hair *et al.*, 2009; Ringle *et al.*, 2014). The only exception was the construct “fiscal incentives”, which yielded a Cronbach’s alpha of 0.295; however, both composite reliability (0.701) and AVE (0.564) were satisfactory, and it was therefore retained in the model.

Table 1 – Convergent Validity, Internal Consistency, and Composite Reliability

	<i>Cronbach's alpha</i>	<i>Composite reliability (rho_c)</i>	<i>Average variance extracted (AVE)</i>
Absorptive capacity	0.913	0.935	0.742
Technological cooperation	0.935	0.951	0.796
Organisational culture	0.928	0.946	0.777
Strategy	0.953	0.966	0.877
Organisational structure	0.753	0.843	0.590
Fiscal incentives	0.295	0.701	0.564
Process innovation	0.832	0.899	0.749
Marketing innovation	0.872	0.913	0.724
Organisational innovation	0.876	0.907	0.619
Market	0.843	0.894	0.680

Source: The authors.

Discriminant validity, assessed using the Fornell-Larcker criterion, is presented in Table 2. The results indicate that, in most cases, the square root of the AVE was greater than the correlations between constructs, thereby satisfying the criterion. An exception was observed in the correlation between absorptive capacity and organisational culture, which exceeded the reference value, suggesting possible conceptual redundancy between these constructs. This issue was further examined in conjunction with collinearity (VIF) in the structural model.

Table 2 – Discriminant Validity: Fornell-Larcker Criterion (1981)

	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>	<i>V</i>	<i>VI</i>	<i>VII</i>	<i>VIII</i>	<i>IX</i>	<i>X</i>
I. Absorptive capacity	0.861									
II. Technological cooperation	0.796	0.892								
III. Organisational culture	0.880	0.733	0.881							
IV. Strategy	0.875	0.836	0.739	0.937						
V. Organisational structure	0.806	0.695	0.793	0.715	0.768					
VI. Fiscal incentives	0.711	0.702	0.594	0.762	0.603	0.751				
VII. Process innovation	0.746	0.819	0.679	0.801	0.609	0.747	0.866			
VIII. Marketing innovation	0.539	0.616	0.563	0.573	0.489	0.481	0.654	0.851		
IX. Organisational innovation	0.765	0.820	0.717	0.786	0.644	0.792	0.839	0.689	0.787	
X. Market	0.729	0.819	0.732	0.749	0.718	0.669	0.692	0.643	0.752	0.824

Source: The authors.

Table 3 presents the results of the structural model. Of the estimated paths, four were statistically significant: technological cooperation and process innovation ($\beta = 0.464$; $p < 0.01$), technological cooperation and organisational innovation ($\beta = 0.355$; $p < 0.01$), fiscal incentives and process innovation ($\beta = 0.279$; $p < 0.01$), and fiscal incentives and organisational innovation ($\beta = 0.384$; $p < 0.001$). The

remaining paths did not reach statistical significance, although some displayed moderately positive coefficients, such as the relationship between market and marketing innovation ($\beta = 0.358$; $p = 0.059$) (Figure 2).

Table 3 – Structural Model Results

	<i>Coefficient</i>	<i>Standard deviation</i>	<i>p-values</i>
Absorptive Capacity → Process Innovation	-0.066	0.208	0.750
Absorptive Capacity → Marketing Innovation	-0.224	0.276	0.417
Absorptive Capacity → Organisational Innovation	-0.004	0.186	0.983
Technological Cooperation → Process Innovation	0.464	0.145	0.001
Technological Cooperation → Marketing Innovation	0.190	0.228	0.403
Technological Cooperation → Organisational Innovation	0.355	0.128	0.006
Organisational Culture → Process Innovation	0.172	0.175	0.325
Organisational Culture → Marketing Innovation	0.280	0.209	0.181
Organisational Culture → Organisational Innovation	0.206	0.145	0.155
Strategy → Process Innovation	0.257	0.169	0.129
Strategy → Marketing Innovation	0.187	0.233	0.421
Strategy → Organisational Innovation	0.050	0.166	0.766
Organisational Structure → Process Innovation	-0.092	0.145	0.525
Organisational Structure → Marketing Innovation	-0.080	0.172	0.642
Organisational Structure → Organisational Innovation	-0.091	0.105	0.387
Fiscal Incentives → Process Innovation	0.279	0.107	0.009
Fiscal Incentives → Marketing Innovation	0.006	0.184	0.976
Fiscal Incentives → Organisational Innovation	0.384	0.110	0.000
Market → Process Innovation	-0.079	0.133	0.554
Market → Marketing Innovation	0.358	0.190	0.059
Market → Organisational Innovation	0.085	0.126	0.501

Source: The authors

In the supplementary analyses, the average VIF was 5.147, which is considered acceptable as it remains below the threshold of 10 (Gujarati; Porter, 2009). The analysis of effect sizes (f^2) indicated small (0.02) and medium (0.15) effects, according to Cohen's (1988) classification. Regarding the model's explanatory power, the adjusted coefficients of determination (R^2) were 0.725 for process innovation, 0.398 for marketing innovation, and 0.761 for organisational innovation. This demonstrates that the model had the greatest explanatory power for organisational innovation, followed by process innovation, with lower explanatory power for marketing innovation.

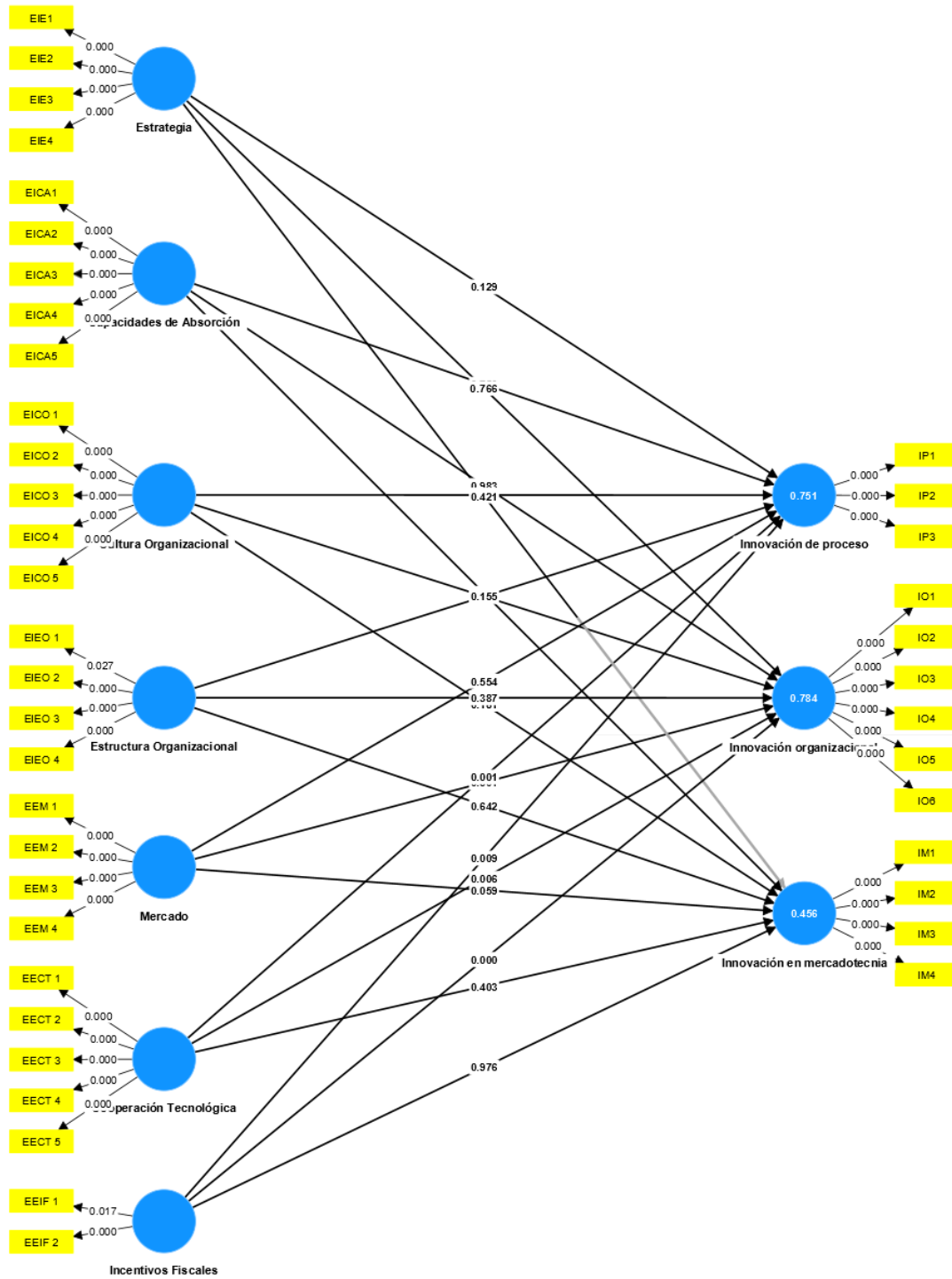


Figure 2 – PLS-SEM Structural Model of Internal and External Determinants of Innovation in Amazonian Aquaculture Organisations

Source: The authors

Aquaculture has grown rapidly and has become a strategic component of contemporary agri-food systems, contributing to food security and employment. At a global level, studies have shown that the economic, social, and environmental pillars can mutually reinforce one another within aquaculture systems, without systematic trade-offs between them (Garlock *et al.*, 2024). This evidence is closely linked to the international emphasis on partnerships and innovation to advance the objectives of the 2030 Agenda (Troell *et al.*, 2023), and to the idea that aquaculture represents a source of animal

protein with a lower environmental footprint than traditional livestock sectors, while also adapting to more demanding sustainability requirements (Bennett *et al.*, 2021; Bohnes *et al.*, 2022; Costello *et al.*, 2020; Springmann *et al.*, 2018).

In this context, the empirical findings indicate that external determinants—particularly technological cooperation and fiscal incentives—are positively and significantly associated with process innovation and organisational innovation. This pattern is consistent with the literature, which emphasises the centrality of collaboration and institutional arrangements in activating and sustaining change in productive sectors. It has been noted that the success of innovation is closely linked to the quality of collaborative relationships (Ferguson, 2005) and that innovative activities are often observed primarily among suppliers and service providers connected to aquaculture, reinforcing the importance of networks that extend beyond production units (Aarstad; Jakobsen, 2020; Aarstad *et al.*, 2023). Furthermore, in the face of environmental concerns and resource constraints, the need for cooperation and for combining technological solutions with improved management practices has also been highlighted, along with policies that promote innovative techniques aimed at more responsible production (Laktuka *et al.*, 2023; Ogello; Munguti, 2016).

On the other hand, the internal factors considered—strategy, culture, organisational structure, and absorptive capacity—did not show significant effects on the innovations analysed. The literature offers useful insights for understanding this result. The adoption of innovations in aquaculture may be limited by capital requirements, funding barriers, and difficulties in accessing equipment, inputs, and training, especially in smaller-scale organisations (Rosgren, 2022; Vecchio *et al.*, 2024). Added to this are cultural influences and routines that affect the acceptance of new practices (Stanfield, 1999), as well as the role of local institutions in creating enabling conditions and embedding innovation within the territory (Kumar, 2018). It has also been noted that without the involvement of the productive sector, research funded by public resources tends to be less relevant and impactful, making openness and effective engagement among actors essential if R&D is to translate into concrete change (Iversen; Hydle, 2023). The effect of the market environment on marketing innovation approached statistical significance, suggesting signs of commercial adjustment that could be further strengthened through differentiation strategies tailored to the regional context (Cojocarú *et al.*, 2020).

The Amazon is a region of high biological diversity and a need for productive alternatives that strengthen livelihoods and reduce pressure on ecosystems. Evidence indicates that innovation processes in aquaculture depend on the social and institutional dynamics that mediate their adoption (Ferreiro; Sousa, 2019). In this sense, it has been suggested that innovation can help make the cultivation of native species viable and strengthen weaker links in the value chain (Vecchio *et al.*, 2024), while the heterogeneity of performance observed globally opens up opportunities for policies and investments capable of improving economic, social, and environmental outcomes where these remain incipient (Garlock *et al.*, 2024). This aligns with the idea that, in the region, there are possible development pathways with a lower carbon footprint per unit of protein and without further agricultural expansion, provided that decisions are guided by evidence and cooperation (Pacheco *et al.*, 2025). At the same time, various studies on sustainability transitions have analysed how innovations can generate multiple impacts on development objectives. These studies offer frameworks for anticipating both synergies and potential trade-offs between economic, social, and environmental goals (Dorninger *et al.*, 2020; Gaitán-Cremaschi *et al.*, 2019).

From a governance perspective, the effectiveness of policy networks is associated with the inclusion of relevant actors, the openness of processes, and participants' perception of outcomes (Krause, 2015). When these conditions are not met, a gap may emerge between stakeholders and policies, resulting in regulations that are poorly targeted or even detrimental to the sector (Green, 2023; Vecchio *et al.*, 2024). At the same time, innovation may also be understood as a vector of institutional development, insofar as governments strengthen the instruments used to promote science, technology, and innovation within the business sector. Overall, the results from San Martín—where technological cooperation and

fiscal incentives were positively associated with process and organisational innovation—are consistent with this trend. Thus, innovative capacity is effectively consolidated when collaborative networks and institutional support enable learning and technical assistance to be translated into lasting organisational and operational changes. This, in turn, strengthens the sector's resilience and its prospects for more balanced development in a complex Amazonian environment.

4 CONCLUSIONS

The analysis of the determinants of innovation in aquaculture organisations in San Martín showed that technological cooperation and fiscal incentives were the factors significantly associated with process and organisational innovation. These results indicate that, in Amazonian contexts, innovation capacity is strongly shaped by external support and institutional coordination, whereas internal organisational factors—such as strategy, structure, culture, and absorptive capacity—have not yet emerged as decisive drivers of change.

This finding highlights the importance of consolidating mechanisms for collaboration and support policies that assist producers in adopting new practices. Technological cooperation contributes to improving the efficiency and quality of production. At the same time, fiscal incentives facilitate the channelling of resources towards changes that strengthen organisational stability and generate benefits beyond the economic sphere, including enhancements to community quality of life and the protection of aquatic environments. In this sense, non-repayable funding programmes act as catalysts, promoting not only producers' competitiveness but also a more balanced relationship between productive activities and the Amazonian environment.

The study has limitations that should be taken into account, such as its exclusive focus on beneficiaries of a national programme and its cross-sectional design, both of which restrict the possibility of generalising the results and establishing causal relationships. Nevertheless, the findings provide valuable evidence for understanding how specific factors influence the development of innovative capacities in Amazonian aquaculture.

Future research could broaden the analysis to other regions of the country, include organisations that are not beneficiaries of support programmes, and incorporate longitudinal studies to observe how innovation capacities evolve over time. It would also be relevant to further examine internal organisational aspects such as intrapreneurship—understood as the capacity to generate and promote innovative initiatives from within organisations—and the role of microcredit as a complementary factor linked to access to resources for the adoption of improvements and innovations. Over time, these may become decisive elements in consolidating a more resilient aquaculture sector capable of addressing environmental challenges.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used Grammarly Pro, Grammarly Inc. for language editing and stylistic polishing only. All scientific content, analysis, and intellectual input were developed and verified by the authors; we take full responsibility for the accuracy and integrity of the manuscript.

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