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Connecting helices, generating solutions: the role of INOVAREPE in modernizing public management in Pernambuco

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Abstract

The digital and sustainable transformation of public management requires innovative, collaborative, and data-driven approaches. In this context, the INOVAREPE program in Pernambuco operates as an open innovation platform, connecting government, academia, the productive sector, and civil society to address public challenges and strengthen the innovation ecosystem. This study examines how the principles of open innovation and Quintuple Helix Theory are applied in the INOVAREPE Program and assesses its contribution to efficiency, sustainability, and innovation in public services. The investigation is grounded in the concepts of open innovation (Chesbrough, 2003) and Quintuple Helix Theory (Carayannis & Campbell, 2010), which emphasize the importance of multisector collaboration and the integration of knowledge, the environment, and sustainable development. This is a quantitative, descriptive, and correlational study based on an online survey administered to 39 program participants. Data were collected through Google Forms and analyzed using descriptive statistics, a t-test, and reliability assessment through the omega coefficient. The findings indicated highly positive perceptions of the program's effects. All hypotheses were confirmed. INOVAREPE proved effective in promoting innovation, efficiency, and sustainability in public management. Despite the sample limitations, the results support the relevance of the proposed theoretical model and highlight the strategic role of multisector collaboration. The study contributes to the empirical validation of open innovation in the public sector and provides evidence for public policies that may be replicated in other contexts. It also stands out as a model for coordinating Quintuple Helix actors in support of sustainable innovation.

Keywords: Open innovation; Public management; Sustainability.

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1. Introduction

The pursuit of sustainable development is driving disruptive transformation in public management, requiring governments to adopt innovative, collaborative, and data-driven approaches to address complex social challenges (Mazzucato, 2018). In this context, open innovation emerges as a promising model that encourages collaboration among different actors to generate creative and effective solutions (Chesbrough, 2003).o processo de

Henry Chesbrough (2003) defines open innovation as the intentional use of knowledge flows into and out of an organization to accelerate internal innovation and expand the external use of innovations.

The state of Pernambuco, Brazil, has distinguished itself in promoting open innovation through several programs, including INOVAREPE, which seeks to foster entrepreneurship and sustainability in practical ways. It focuses primarily on solutions that generate positive environmental and socioeconomic impacts by connecting students, professors, and universities to address strategic challenges through collaborative partnerships. This approach is consistent with OECD recommendations emphasizing the importance of regulatory environments and policies that support collaboration among actors to promote innovation, efficiency, and sustainable development, understood as the integration of economic growth, social inclusion, and environmental preservation to ensure the well-being of present and future generations (OECD, 2022).

INOVAREPE is an open innovation program designed to foster entrepreneurship and sustainability in Pernambuco by mobilizing students, professors, universities, government, and society to collaborate in developing solutions to the state's strategic challenges, thereby strengthening Pernambuco's innovation ecosystem. The initiative provides a practical collaborative environment, offering training, multidisciplinary team formation, and the development of minimum viable products (MVPs) with technical and economic feasibility. Recent studies on open innovation indicate that expanding organizational boundaries enables organizations to access a broader range of ideas, reduce research and development costs, and accelerate innovation processes, reinforcing the effectiveness of initiatives such as INOVAREPE (Chesbrough, 2020).

The program is implemented by the University of Pernambuco (UPE) and the Federal University of Pernambuco (UFPE), with funding from the Pernambuco State Department of Science, Technology and Innovation, the Pernambuco Foundation for Science and Technology Support (FACEPE), the Government of Pernambuco, and the INOVA.PE Innovation Agency.

The initiative provides soft-skills training, mentoring, and project development, contributing to the education of students and professionals in strategic fields and aligning with SDG 4 - Quality Education.

By offering innovation grants, access to investors, and opportunities for project incubation, the initiative creates concrete conditions for developing new businesses while strengthening participants' qualifications and reducing barriers to entrepreneurship. These actions support job and income generation and innovative solutions with sustainable growth potential, contributing to the dynamism of the local economy. In this regard, the initiative aligns with SDG 8 - Decent Work and Economic Growth, proposed by the United Nations, because it simultaneously promotes entrepreneurship, productivity, and the creation of sustainable economic opportunities.

The program is a practical example of open innovation applied to public management, promoting the development of technological solutions to government challenges and strengthening partnerships among government, academia, and the private sector. It therefore contributes to SDG 9 - Industry, Innovation and Infrastructure, proposed by the United Nations, which seeks to promote sustainable industrialization, foster innovation, and expand access to resilient infrastructure. The initiative stimulates the creation and application of technologies, strengthens the innovation ecosystem, and encourages collaboration among different actors for technological development.

As its general objective, INOVAREPE seeks to solve local problems faced by the Government of the State of Pernambuco and contribute to the sustainable development of cities. This objective demonstrates its connection with SDG 11 - Sustainable Cities and Communities, proposed by the United Nations, which aims to make cities more inclusive, safe, resilient, and sustainable. The initiative promotes innovative solutions to urban challenges, improves public management, and encourages practices that enhance the population's quality of life.

The INOVAREPE Journey therefore reflects the promotion of innovation as a tool for transforming public management and improving the quality of life of Pernambuco society. Academic studies on this topic demonstrate the need for deeper investigation of this open innovation model in the context of state public administration in Brazil, especially regarding its effectiveness in advancing administrative efficiency, innovation, and participatory governance and the possibility of replicating and developing insights adapted to different realities.

The program is still underway, which means that academic studies on the topic remain under development, particularly given the growing importance of open innovation as a strategy for modernizing public management (Chesbrough, 2003). Against this background, the present study is justified not only by its originality but also by the need to deepen understanding of how INOVAREPE can contribute to generating innovative solutions, promoting sustainability, and strengthening Pernambuco's public innovation ecosystem.

By examining the program through the theoretical perspectives discussed above, the study seeks to address relevant gaps and provide theoretical and practical evidence for advancing innovative public policies.

In this context, the study is expected not only to validate INOVAREPE as an innovative public-policy management model but also to inspire other initiatives seeking creative and effective solutions to contemporary public-management challenges. The guiding research question is: how are the principles of Open Innovation and Quintuple Helix Theory applied in the INOVAREPE Program, and how does the program contribute to efficiency, sustainability, and innovation in public services?

Using a quantitative approach, the study discusses the principles applied in the INOVAREPE program and highlights its contribution to efficiency, sustainability, and innovation in public services.

2. Theoretical framework

2.1. Open Innovation in the INOVAREPE Program

According to the Organisation for Economic Co-operation and Development (OECD), innovation refers to the implementation of a new product or a significant improvement to an existing product and may also involve a new process or organizational method in business practices (OECD, 2004).

Open Innovation, as proposed by Chesbrough (2003), emphasizes collaboration, knowledge sharing, and the integration of external and internal ideas to accelerate and improve innovation in public and private organizations. In the context of INOVAREPE, this is reflected in the government's openness to partnerships with universities, companies, civil society, and other actors, promoting the co-creation of solutions to public challenges and enhancing idea generation, efficiency, and the sustainability of solutions. The following research hypotheses are therefore proposed:

H1: Multisector collaboration positively affects the efficiency of projects developed within INOVAREPE.

H3: Multisector collaboration is associated with the identification and assimilation of external opportunities.

H4: The use of digital technologies facilitates collaboration and co-creation among program actors.

H7: The existence of institutional barriers negatively moderates the relationship between multisector collaboration and program outcomes.

2.2. Quintuple Helix Theory in the INOVAREPE Program

Quintuple Helix Theory (Carayannis & Campbell, 2010) expands the innovation model by integrating five helices: government, academia, the productive sector, civil society, and the environment. INOVAREPE's

success depends on effective coordination and collaboration among these actors, promoting an innovative and sustainable ecosystem aligned with the SDGs. Joint action by these five actors is essential to creating an innovative and sustainable ecosystem aligned with the Sustainable Development Goals (SDGs) and the COP30 agenda. The program seeks not only technological innovation but also institutional transformation, environmental sustainability, and social engagement.

The following hypotheses are therefore grounded in this framework:

H2: Multisector collaboration positively influences the quality and sustainability of public services.

H5: Multisector collaboration strengthens the innovation ecosystem.

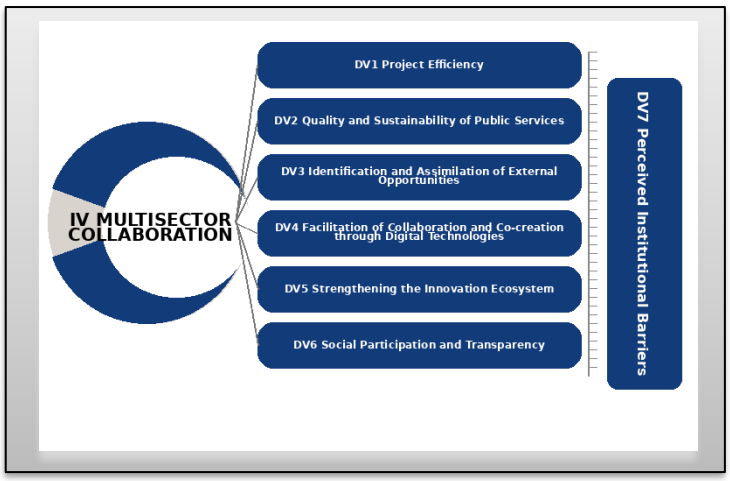
H6: Collaboration among Quintuple Helix actors contributes to greater social participation and transparency in program processes.

H7: The existence of institutional barriers negatively moderates the relationship between multisector collaboration and program outcomes.

Based on the relationships established among the constructs, a theoretical model was developed, as shown in Figure 1, which systematizes the hypotheses. The proposed model places multisector collaboration (IV) as the independent variable at the top, its relationships with the six dependent variables (DV1 to DV6) in the center, and perceived Institutional Barriers (DV7) as a moderating variable influencing these relationships. Thus, multisector collaboration among Quintuple Helix actors positively affects efficiency, sustainability, innovation, and social participation in the context of INOVAREPE.

Figure 1

Theoretical model



Source: The authors (2025).

Table 1 presents the structure and characterization of the variables included in the proposed theoretical model, with their classification as independent or dependent variables. For each variable, it specifies the

conceptual description, operational definition, number of instrument items, theoretical references, measurement scales, and corresponding indicators.

Table 1

Structure and Characterization of the Variables in the Theoretical Model

DIMENSION (VARIABLE)	QUESTIONS	DEFINITION	SCALE	THEORETICAL REFERENCE	INDICATOR
Multisector Collaboration (IV)	1	Refers to the degree of interaction, coordination, and cooperation among the different actors involved in the INOVAREPE Program, including government, academia, the productive sector, civil society, and the environment (Quintuple Helix model).	Dichotomous: Yes / No	Carayannis & Campbell (2010); Chesbrough (2003)	Integration among helices (government, academia, productive sector, civil society, and environment)
Project Efficiency (DV-1)	1	Refers to the ability of projects implemented by the program to achieve their objectives effectively while optimizing resources and processes.	Likert scale (1 = Strongly disagree; 7 = Strongly agree)	Chesbrough (2003); Churchill (1979); Hair et al. (2019)	Operational efficiency; Optimization of resources and processes
Quality and Sustainability of Public Services (DV-2)	1	Assesses the impact of collaboration on improving the quality of public services and incorporating sustainable practices.	Likert scale (1 = Strongly disagree; 7 = Strongly agree)	Carayannis & Campbell (2010); Chesbrough (2003)	Quality improvement; Incorporation of sustainable practices

DIMENSION (VARIABLE)	QUESTIONS	DEFINITION	SCALE	THEORETICAL REFERENCE	INDICATOR
Identification and Assimilation of Opportunities (DV-3)	1	Measures the program's ability to capture and integrate opportunities, ideas, and resources from outside the government context.	Likert scale (1 = Strongly disagree; 7 = Strongly agree)	Chesbrough (2003); Tidd et al. (2008)	Openness to innovation; Capture of external ideas and resources
Digital Technologies for Co-creation (DV-4)	1	Analyzes how the use of digital technologies contributes to collaboration, co-creation, and innovation among program actors.	Likert scale (1 = Strongly disagree; 7 = Strongly agree)	Carayannis & Campbell (2010); Chesbrough (2003); Hair et al. (2019)	Use of digital technologies; Facilitation of collaboration and co-creation
Strengthening the Innovation Ecosystem (DV-5)	1	Assesses the extent to which the program contributes to developing and consolidating an environment conducive to open and sustainable innovation.	Likert scale (1 = Strongly disagree; 7 = Strongly agree)	Chesbrough (2003); Carayannis & Campbell (2010)	Open ecosystem; Sustainable innovation
Social Participation and Transparency (DV-6)	1	Refers to the degree of civil-society involvement and the promotion of transparency in the program's processes and outcomes.	Likert scale (1 = Strongly disagree; 7 = Strongly agree)	Carayannis & Campbell (2010); Quadruple/Quintuple Helix Model	Social inclusion; Access to information; Transparency
Institutional Barriers (DV-7)	1	Measures difficulties perceived by participants, such as bureaucracy and institutional obstacles, that may limit the achievement of program objectives.	Likert scale (1 = Strongly disagree; 7 = Strongly agree)	Churchill (1979); Hair et al. (2019); studies of barriers to public-sector innovation	Perceived obstacles such as bureaucracy and institutional rigidity

Source: The authors (2025).

3. Materials and methods

This study aims to analyze how the principles of open innovation and Quintuple Helix Theory are applied in the INOVAREPE Program and how the program contributes to efficiency, sustainability, and innovation in public services.

Following John W. Creswell (2014) and the objectives established for this study, a quantitative, descriptive, and correlational approach was adopted, using a single cross-sectional design and structured online survey questionnaires administered through Google Forms. Participants were reached through WhatsApp dissemination. Quantitative survey research enables the collection of a broad range of responses from a target population through a closed-ended questionnaire (Hair Jr., Page, & Brunsveld, 2019).

The unit of analysis is the INOVAREPE Project, including all groups involved in the program, such as university representatives, students, companies, civil-society members, solution developers, and public-innovation specialists. Given the exploratory and applied nature of the study, non-probability purposive sampling was adopted, characterized by the deliberate selection of participants considered most appropriate for the study according to criteria established by the researcher (Creswell, 2014). This technique was selected because it enables the strategic recruitment of individuals with relevant knowledge and experience of the phenomenon under investigation and supports representation of the five actors in the Quintuple Helix model.

This method is widely used to collect data at a single point in time, enabling analysis of relationships among variables in a specific population (QuestionPro, 2025). The development and administration of the data-collection instrument followed the methodological guidelines proposed by Hair Jr. et al. (2023) to ensure the validity and reliability of the data obtained.

Data were collected through a structured questionnaire comprising eight items, seven of which were assessed on a seven-point Likert scale (1 = "Strongly disagree" to 7 = "Strongly agree") and one dichotomous item (Yes/No). The instrument was developed from scales widely validated in the scientific literature and adapted to the context of the INOVAREPE Program and the Quintuple Helix model.

The theoretical basis used to construct the questionnaire draws on internationally recognized studies of open innovation, interorganizational collaboration, and innovation ecosystems. Henry Chesbrough's (2003) work Open Innovation: The New Imperative for Creating and Profiting from Technology presents the foundations, mechanisms, and effects of open innovation in organizational environments and informed the development of items related to multisector collaboration and the integration of external ideas.

In addition, the conceptual structure of the Quintuple Helix model was based on the work of Elias G. Carayannis and David F. J. Campbell (2010), titled Triple Helix, Quadruple Helix and Quintuple Helix and How Do Knowledge, Innovation and the Environment Relate to Each Other? A Proposed Framework for a Trans-disciplinary Analysis of Sustainable Development and Social Ecology. The authors deepen understanding of the integration of government, academia, the productive sector, civil society, and the environment as essential dimensions in promoting sustainable innovation.

The questionnaire was therefore developed on the basis of these theoretical contributions, ensuring scientific alignment with open innovation and collaborative development in the context of the INOVAREPE Program. The use of a seven-point Likert scale follows the methodological recommendations of Churchill (1979) and Hair et al. (2019), who support its robustness for measuring organizational constructs and perceptions of institutional barriers.

The instrument was administered online through Google Forms and sent directly to participants through the program's institutional WhatsApp groups between June 24 and July 8, 2025, as shown in Table 2. The objective was to assess participants' perceptions of the degree of collaboration among the helices, the use of digital technologies, the barriers encountered, such as bureaucracy, and perceived outcomes in terms of efficiency, sustainability, and participation.

Table 2
Data collection

Respondent profile	**INOVAREPE Program participants**
Data collection period	June and July 2025
Data collection duration	15 days
Mode	Online - messages introducing the study and requesting participation.

Source: The authors (2025).

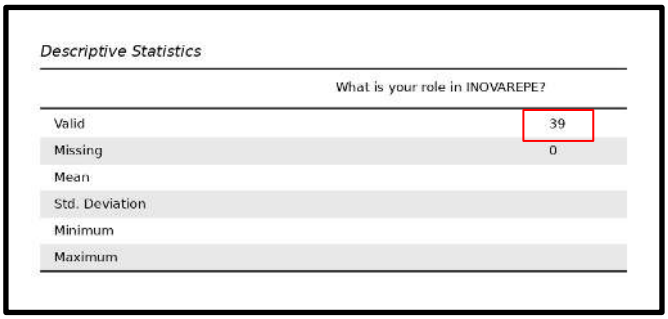
The collected data were processed using JASP (Jeffrey's Amazing Statistics Program), version 0.19.3.0. Descriptive statistical analyses and internal-consistency calculations using the omega coefficient followed the methodological recommendations of Hair Jr. et al. (2016) and the psychometric updates discussed by Viladrich et al. (2017), who identify omega as a more robust and appropriate measure than Cronbach's alpha in many contexts.

4. Results and discussion

Based on the descriptive analysis performed in JASP, the following results summarize respondents' perceptions of the INOVAREPE Program in relation to the theoretical constructs of Open Innovation and the

Quintuple Helix. The initial sociodemographic analysis characterized a sample of 39 valid respondents, with no missing data, as shown in Table 3.

Table 3
Sample



Descriptive Statistics

	What is your role in INOVAREPE?
Valid	39
Missing	0
Mean	
Std. Deviation	
Minimum	
Maximum	

Source: JASP database (2025).

In this study, the sample was characterized according to the analytical structure of Quintuple Helix Theory, which proposes synergistic interaction among five fundamental spheres for strengthening innovation ecosystems: academia, the productive sector, government, civil society, and the environment (Carayannis & Campbell, 2010). The profiles of the 39 respondents, shown in Table 4, reveal a marked concentration of participants linked to academia: 71.795% were students and 10.256% were professors, totaling 82.051% of the sample.

This distribution indicates the predominance of the educational and scientific sector in the INOVAREPE Program, which is consistent with the emphasis placed on universities as centers for generating knowledge, research, and innovation in the Triple Helix model and further developed in the Quintuple Helix approach (Etzkowitz & Leydesdorff, 2000; Carayannis & Campbell, 2010).

The productive sector, comprising partner companies (5.128%), startups (2.564%), and accelerators (2.564%), represented 10.256% of participants, demonstrating the presence of the economic and entrepreneurial sector in the innovation ecosystem analyzed. Government representatives accounted for 7.692% of respondents, indicating institutional and political participation in the development and implementation of program initiatives and reinforcing the role of the public sector as one of the pillars of collaborative innovation (Carayannis & Campbell, 2010).

Although civil society and the environment were not explicitly identified in the sample, the presence of accelerators and startups may indicate some interface with these actors, albeit in limited proportions. Their lower representation suggests opportunities to expand the inclusion of civil society and environmental issues in the program, thereby strengthening sustainability and social participation, which are central elements of

the Quintuple Helix model and fundamental to sustainable innovation in the current context (Carayannis & Campbell, 2010; Morais et al., 2022).

Table 4
Sample frequency

Frequency Tables

Frequencies for What is your role in INOVAREPE?

Role in INOVAREPE	Frequency	Percent	Valid Percent	Cumulative Percent
Developer, digital accelerator, digital mentor, advanced AI	1	2.564	2.564	2.564
Partner company	2	5.128	5.128	7.692
Student	28	71.795	71.795	79.487
Government	3	7.692	7.692	87.179
Professor	4	10.256	10.256	97.436
Startup	1	2.564	2.564	100.000
Missing	0	0.000		
Total	39	100.000		

Source: JASP database (2025).

The reliability of the scale was assessed using the omega coefficient (ω), which is more appropriate than Cronbach's alpha in contexts of unidimensionality and factor modeling. Recent studies emphasize that omega provides a more precise estimate of internal consistency, particularly when items have different factor loadings (Zinbarg et al., 2005; Dunn et al., 2014). The value obtained was ω = 0.808, with a standard error of 0.047 and a 95% confidence interval from 0.716 to 0.900.

This result indicates internal consistency of the scale, suggesting that the assessed items are strongly correlated and contribute coherently to measuring the proposed theoretical construct. According to the reference criteria (Revelle & Zinbarg, 2009), omega values above 0.80 are considered good and values above 0.90 excellent.

The finding of unidimensional reliability suggests that the data fit the scale's theoretical proposal well, supporting its suitability for subsequent statistical analyses, such as hypothesis testing or predictive modeling.

Table 5
Reliability statistics

Frequentist Scale Reliability Statistics

Coefficient	Estimate	Std. Error	95% CI Lower	95% CI Upper
Coefficient ω	0.808	0.047	0.716	0.900

Source: JASP database (2025).

The descriptive analysis presented in Table 6 covered eight variables measured on a Likert scale from 1 to 7, using the indicators mean, median, mode, and standard deviation to assess participants' perceptions of the impacts and limitations of the INOVAREPE Program. The items reflect different dimensions of INOVAREPE's impact according to the adopted theoretical model. All variables had 39 valid responses and no missing data.

Most variables had means above 6, indicating predominantly positive perceptions of INOVAREPE's effects on fostering public-sector innovation.

Means ranged from 5.692 to 6.615 on a scale from 1 (strongly disagree) to 7 (strongly agree), with modes and medians predominantly equal to 7, indicating strong agreement with the program aspects assessed.

The three variables with the highest means were "Does INOVAREPE encourage collaboration among different actors?" (M = 6.615; SD = 0.590), followed by "Does INOVAREPE contribute to creating a public-sector innovation ecosystem?" (M = 6.513; SD = 0.683), and "Is the knowledge acquired through the INOVAREPE program applied to improve public processes or services?" (M = 6.359; SD = 0.743).

These results support the assumptions of Open Innovation (Chesbrough, 2003), which emphasizes interaction between internal and external agents to improve processes and generate public value. The strong perception of multisector collaboration also reflects adherence to the Quintuple Helix model (Carayannis & Campbell, 2010), particularly the academic, governmental, and productive-sector helices.

The variable with the lowest mean was the effectiveness of information and technology exchange among participants, with a mean of 5.692 and a standard deviation of 1.559. This result points to a potential concern regarding internal coordination, suggesting that although collaboration occurs institutionally, knowledge-sharing mechanisms among participants may not yet be sufficiently consolidated.

The variable concerning bureaucracy as a barrier to innovation had a mean of 6.410 and a standard deviation of 0.938, indicating strong agreement on the existence of institutional obstacles, as reported in the literature on public-sector innovation (Tõnurist, Lember, & Kattel, 2017). This finding reinforces the need for administrative restructuring that supports agility and the co-creation of solutions.

Finally, the promotion of transparency and social participation received a positive assessment, with a mean of 5.744 and a standard deviation of 1.186. Participants therefore recognized the program's efforts to integrate civil society, even though this group had limited representation in the sample.

Table 6

Descriptive statistics for the sample

Descriptive Statistics

	External opportunities identified	Knowledge applied to improve public services	Collaboration among different actors	Effective information and technology exchange	Policies encourage collaborative sustainable innovation	Contribution to a public-sector innovation ecosystem	Government bureaucracy as an innovation barrier	Transparency and social participation promoted
Valid	39	39	39	39	39	39	39	39
Missing	0	0	0	0	0	0	0	0
Mode	7.000*	7.000*	7.000*	6.000*	7.000*	7.000*	7.000*	7.000*
Median	7.000	7.000	7.000	6.000	7.000	7.000	7.000	6.000
Mean	6.205	6.359	6.615	5.692	6.333	6.513	6.410	5.744
Std. Dev.	1.218	0.743	0.590	1.559	0.955	0.683	0.938	1.186
Minimum	2.000	5.000	5.000	1.000	3.000	4.000	3.000	3.000
Maximum	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000

* Multiple modes exist; the first value is reported.

Source: JASP database (2025).

To verify the statistical significance of respondents' perceptions of the impacts of the INOVAREPE Program, a one-sample t-test was applied, with the null hypothesis assuming that the population mean of the responses was equal to zero, indicating no agreement. The variables were tested individually, as shown in Table 7.

Table 7
One-sample t-test

One Sample T-Test

	t	df	p
Has INOVAREPE facilitated the identification of external innovation opportunities?	31.819	38	< .001
Is knowledge acquired through INOVAREPE applied to improve public processes or services?	53.452	38	< .001
Does INOVAREPE encourage collaboration among government, academia, the private sector, civil society, and the environment?	70.014	38	< .001
Is the exchange of information and technologies among INOVAREPE participants effective?	22.808	38	< .001
Do public policies associated with INOVAREPE encourage collaborative and sustainable innovation?	41.410	38	< .001
Does INOVAREPE contribute to building a public-sector innovation ecosystem?	59.521	38	< .001
Does government bureaucracy constitute a challenge to implementing the innovations proposed by INOVAREPE?	42.677	38	< .001
Does INOVAREPE promote transparency and social participation in public management?	30.248	38	< .001

Note. For the Student t-test, the alternative hypothesis specifies that the mean differs from 0.
Note. Student's t-test.

Source: JASP database (2025).

The results showed high and statistically significant t values ($p < .001$) for all variables analyzed, as presented in Table 7. This pattern indicates that the mean response to every statement differed significantly from zero, revealing strong participant agreement with the positive impacts attributed to the INOVAREPE Program.

The highest t values were observed for collaboration among different actors ($t = 70.014$; $p < .001$), the application of knowledge to improve public services ($t = 53.452$; $p < .001$), and the contribution to building a public-sector innovation ecosystem ($t = 59.521$; $p < .001$). These findings support the hypothesis that the program significantly promotes multisector integration, open innovation, and the practical use of knowledge, in line with the theoretical assumptions of the Quintuple Helix (Carayannis & Campbell, 2010) and Open Innovation (Chesbrough, 2003).

The variable related to institutional barriers also showed a significant result, particularly the perception of bureaucracy as a challenge to implementing innovations ($t = 42.677$; $p < .001$). This finding reinforces evidence from previous studies of administrative obstacles to public-sector innovation (Tõnurist, Lember, & Kattel, 2017), indicating that relevant institutional barriers persist despite the advances provided by the program.

The lowest t statistic was recorded for the variable concerning the effectiveness of information and technology exchange ($t = 22.808$; $p < .001$). Although still highly significant, its lower magnitude suggests room for improvement, especially in strengthening communication and co-creation flows among participants.

The hypothesis analysis confirmed the robustness of the proposed theoretical model. H1, which states that INOVAREPE facilitates the identification of external innovation opportunities, was confirmed ($t(38) = 31.819$; $p < .001$), reflecting respondents' positive perceptions of the promotion of open innovation (Chesbrough, 2003).

H2, concerning the application of acquired knowledge to improve public services, yielded $t(38) = 53.452$; $p < .001$, confirming that the program helps transform knowledge into innovative public-sector practices.

H3, concerning the encouragement of collaboration among different sectors in accordance with Quintuple Helix principles, was strongly confirmed ($t(38) = 70.014$; $p < .001$). This was the highest t statistic in the analysis and validates the program's multisector coordination (Carayannis & Campbell, 2010).

H4, concerning the effectiveness of information and technology exchange among participants, was also confirmed ($t(38) = 22.808$; $p < .001$), although its lower value indicates a less intense perception of this dimension.

H5, which examines whether the public policies associated with the program encourage collaborative and sustainable innovation, yielded $t(38) = 41.410$; $p < .001$. The hypothesis was confirmed, demonstrating the alignment of policy guidelines with the principles of sustainability and collaboration.

H6, concerning the program's contribution to building a public-sector innovation ecosystem, was confirmed with $t(38) = 59.521$; $p < .001$, demonstrating the consolidation of innovation networks involving multiple actors (Etzkowitz & Leydesdorff, 2000).

H7, concerning the perception of bureaucracy as a barrier to innovation, was also confirmed ($t(38) = 42.677$; $p < .001$), consistent with the literature on administrative challenges to innovation (Tõnurist et al., 2017).

Finally, H8, which assesses the promotion of transparency and social participation, was confirmed ($t(38) = 30.248$; $p < .001$), indicating a favorable perception of the program's role in strengthening social engagement in public management.

In summary, despite variations in the t values, all hypotheses in the theoretical model were confirmed, demonstrating the positive effects of the INOVAREPE Program on key dimensions of open innovation and Quintuple Helix Theory.

5. Conclusions

The statistical tests confirmed all hypotheses formulated in this study. The descriptive analyses and t-tests revealed broadly positive perceptions of the effects of multisector collaboration across the different dimensions of the INOVAREPE Program. The principal strengths were project efficiency, integration among Quintuple Helix actors, and reinforcement of the innovation ecosystem. Nevertheless, the findings identified a need to improve information-exchange mechanisms and address institutional barriers, such as bureaucracy, that still limit the full scope of innovative actions. These findings reinforce the relevance of the adopted theoretical model and contribute to consolidating INOVAREPE as an emblematic case of innovation in Pernambuco.

Despite the statistically significant results, several limitations must be recognized when interpreting the findings. The sample included 39 respondents, representing only a portion of all INOVAREPE Program participants. Although the sampling design followed appropriate statistical parameters, with a 95% confidence level and an estimated margin of error of approximately 15%, the small sample size and non-probability selection restrict the generalization of results to the program's entire population. Even so, the data provide relevant and consistent evidence that contributes to understanding INOVAREPE's effects on the dimensions analyzed and offers a valid basis for future research and the improvement of public policies for public-sector innovation.

In view of these limitations, the study creates opportunities for new investigations that deepen and broaden understanding of the effects of the INOVAREPE Program in the context of public innovation.

From an academic perspective, future studies should expand the size and diversity of the sample by using probability-sampling techniques and engagement strategies that support equitable representation of the five helices defined in Quintuple Helix Theory. This would enable a more robust and comparative analysis of the different actor profiles in the innovation ecosystem.

The adoption of mixed methods is also recommended, integrating qualitative approaches such as semi-structured interviews, focus groups, or case studies with quantitative instruments. This methodological triangulation could provide greater analytical depth and reveal contextual nuances that standardized questionnaires do not capture.

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