



Modelling the triple helix system innovation of the main economies from Latin America: a coalitional game theory approach

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Abstract

This paper investigates the individual and collective scientific contributions carried out by the Triple Helix (University, Industry, and Government) in the areas that are considered of significant impact on innovation, such as Science, Technology, Engineering, and Mathematics (STEM) in the leading economies of Latin American, a zone with limited innovation systems and has experienced many changes in its political and economic structure in recent years. Three cooperative game theory metrics (core, shapley value, and nucleolus) were used to model each player's individual and collective strength to create and maintain synergy. Bibliometric information on STEM areas was collected from the innovation systems of Brazil, Mexico, Chile, and Argentina; all this information was gathered from the Web of Science for ten years (2010–2020). The findings highlight that while universities play a central role in all four countries, government and industry involvement varies, with notable individual government participation in Brazil, Argentina, and Mexico; this scenario reflects that research is often conducted in isolation, marked by agility rather than collaborative efforts, frequently impeded by the extensive time required for organization and navigating bureaucratic processes. In contrast, Chile's approach to collaboration, integrating government, industry, and universities, stands out for its efficient synergy and communication; it leverages the universities' deep expertise, ensuring a balanced and effective participation in research across all sectors. This analysis reveals the diverse dynamics and collaborative patterns in these Latin American countries.

Keywords Game theory · Stem · Core · Shapley value · Nucleolo · Triple helix

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Introduction

Innovation is creating knowledge to generate robust solutions and products that increase productivity in society, which is considered the driving force in the information era (Øivind Strand and Leydesdorff 2013). It is a cumulative process of organizational decisions, which begins from generating an idea to its implementation phase (Popadiuk and Choo 2006; Callens and Verhoest 2023). The Triple Helix model, which describes the relationship between University, Industry, and Government (U–I–G), was introduced by Etzkowitz and Leydesdorff (1998). This model explains that in a post-industrial stage in a technological and knowledge infrastructure context, the main components of this helix must evolve to create synergy in their institutional relationships to benefit from its three core points: the economic dynamics of the market, the dynamic scientific production, and the dynamic centralization of governmental power (Cai and Amaral 2021). This innovation paradigm has been studied from the perspective of several domains mention Park thanks to the availability of enormous quantities of information (big data) about different stakeholders, paired with constantly improving computational capacity, which have allowed many researchers to explore the triple helix theory in various fields such as computer science, scientometric, informetricians, etc. (Skoric 2014; Cai and Etzkowitz 2020).

The synergy of an innovation system can be understood as the other result obtained by interacting two or more actors; the given work could not have occurred without interaction between each system member. Researchers have created different synergy measures that produce different results, each metric has limitations and uses, and a specific metric cannot be correct (Timme et al. 2014). Some authors propose bibliometric indicators (Meyer et al. 2014); others offer metrics based on information theory using Shannon entropy (Leydesdorff and Park 2014). There are other approaches to measuring synergy; one notable example is the work of Perc (2010), who examines the growth and structure of Slovenia's scientific collaboration network over the past 50 years. The author uses the small worlds hypothesis and the preferential attachment theory to explain the network structure and finds that the network has evolved from a fragmented structure to a highly connected one; the results suggest that science in Slovenia is well-cared for and that there is room for continued growth in the number of scientists that can be sustained. Sunahara et al. (2021) comprehensively analyzed the relationship between yearly publication numbers and average journal-impact metrics for the Brazilian scientific elite; the results revealed this association's discipline-specific and career-age-dependent nature and the trends observed among researchers with outlier and non-outlier performance.

Recent research has used bibliometric information like the number of papers published as based-metric to study synergy (Mêgnigbêto 2018b). Patents can also be used as a metric and are gaining popularity recently due to their great commercial value. They are considered a mechanism of exploitation of knowledge (Patra and Muchie 2018; Meyer et al. 2003; Tukoff-Guimarães et al. 2021). In the global landscape, especially in knowledge-based societies, U–I relationships are decisive for the technological growth of a country. Due to reduced public resources, the university has been forced to follow a path where its publications have a direct economic outlet (Vesperi 2017; Ito and Watanabe 2021; Zhang et al. 2019). The industry, on its side, has the financial resources to invest but has limitations in the aspect of generating knowledge by its means; both needs have resulted in U–I collaboration that, in recent years, has allowed the spread of start-ups or academic spin-offs that have led to the creation of thousands of jobs (Sutrisna et al. 2021). U–G has had a stable relationship; governments are concerned that scientific production and its use in

the productive sphere are effective. The lack of efficiency would lead to the risk of loss of competitiveness, job losses, and lack of external financing, which would cause social pressure on the government (Etzkowitz and Leydesdorff 1998; Leydesdorff and Meyer 2003). U–I–G interactions further emphasize these interests, and many emerging countries are fostering this grand coalition to better their position in global economic and innovative competition (Kruss and Visser 2017; Fidanoski et al. 2022).

Triple helix has been analyzed using game theory; Dubina was the first who formalize the structure of a game within an innovation system (Dubina 2015), Mênigbêto used metrics of cooperative games such as core, Shapley value, and the nucleolus to measure the synergy of the innovation systems of South Korea and West Africa based on the number of publications of each of its actors (Mênigbêto 2018b). It is considered that scientific publications are an excellent indicator to measure the “research health” of a country; however, publications that come from areas such as Science, Technology, Engineering, and Mathematics (STEM) may reflect a more precise knowledge exploitation mechanism that helps to understand the real impact on the creation of academic spin-off. OECD establishes that collaboration and research in STEM fields are crucial for the economic and technological development of a country (OECD et al. 2013) STEM research is fundamental for the potential to lead discoveries that encourage innovative applications with a significant impact on how people live (Zhuang et al. 2021). This is especially vital for emerging nations, including those in Latin America, where such advancements can drive their developmental journey and narrow global innovation disparities. However, studies focusing on innovation in emerging countries, particularly Latin America, are sparse. This paper aims to address this gap, contributing to the analysis and understanding of innovation systems in these nations.

The availability of bibliometric data from reliable sources demands that the analysis methodologies be easy to compare in order to have a clear idea about the status of an innovation system (Paswan et al. 2022). The scientific evidence is clear, the countries that compete for the most are the ones that innovate (Pece et al. 2015). Therefore, it is necessary to have a frame of reference to summarize the advances in policies that promote a country’s advancement in innovation. For this reason, many approaches have been developed to measure innovation systems’ impact (Jovanović et al. 2022; Mênigbêto 2018a; Xu and Liu 2017; øivind Strand and Leydesdorff 2013) by incorporating factors such as R &D spending, patent creation, and tech startups. Further, they examine the conduciveness of policy environment and socio-economic outcomes triggered by innovation, shaping a comprehensive outlook on a nation’s innovation landscape. We consider that game theory offers an interesting approach that allows synthesizing information based on each player’s individual and collective participation; it also has flexible metrics that consider criteria such as fairness and coexistence, analyzing the results from different contexts. Pragmatically, it considers possible agreements or coalitions between actors, measuring whether each actor has synergy to form agreements with other interested parties.

Measuring cooperation is crucial for understanding the direction and impact of policies and identifying whether we are moving towards greater integration or experiencing setbacks. The ability to quantify and analyze this cooperation through game theory provides policymakers, innovators, and scholars with a powerful tool to assess and guide the development of collaborative strategies. The importance of game theory lies in its ability to offer an accessible, robust, and visual application that efficiently quantifies the synergy among the significant players in an innovation system. Additionally, their flexible nature allows for the adaptation of models as new players enter the system or as the goals and relationships within the system evolve. This adaptability is essential in the rapidly changing context, where new technologies and policies can significantly alter stakeholder dynamics.

Furthermore, our study's application of game theory opens avenues for future research to delve deeper into the strategic foundations of U–I–G collaborations. Future studies might explore alternative game-theoretic models to predict the outcomes of different policy interventions or assess the impact of technological innovation on collaboration strategies. By extending the application of game theory to other contexts and incorporating multifaceted metrics such as patent analysis (Tukoff-Guimarães et al. 2021; Meyer et al. 2014), citations (Leydesdorff 2013), and economic outcomes, subsequent research can build on our work to offer evidence-based insights into the mechanics of innovation systems.

In this context, this paper analyzes the innovation capacities of the major Latin American economies using game theory methods. The study assesses the Triple Helix synergies using allocation metrics from cooperative game theory. The paper aims to answer the following questions: Who are the most important actors in each country? Is the relationship homogeneous or not between countries? To answer these questions we have collected the data of the STEM scientific articles published for each country and analyzed the interactions and synergies for knowledge production under the Triple Helix. Along the paper, we assessed the collaboration between universities, government, and industry using the Shapley Value and Nucleolus.

Latin American game

Game theory background

Game theory is a mathematical formalization of conflicts between two or more players (understand players as people or institutions) that seek to optimize their interests based on rationality. The game theory was postulated by the mathematician John Von Neumann and economist Oskar Morgenstern in the famous book *Theory of Games and Economic Behavior* (Von Neumann and Morgenstern 1944).

The game theory defines a game structure through four essential elements:

1. **Player:** The participants in a game who decide their strategies.
2. **Strategies set:** It is the set of all strategies available to all players.
3. **Payoff function:** It is the utility that each player receives for the selected strategy.
4. **Information:** The information available to a player to analyze the decision scenarios that other players can make. Decisions can be static or dynamic, depending on the context in which the game takes place.

Game Theory comprises two branches: cooperative games and non-cooperative games. In cooperative games, players compete and cooperate to form coalitions to create added value. In non-cooperative games, players' actions are focused on maximizing their individual decisions based on the information available to each player. Therefore, cooperative games are called coalitional, and non-cooperative games are procedural (Chatain 2016).

Rule of the Latin America triple helix game

The game is defined by determining the actors involved in the triple helix innovation systems, actions within the game will be “cooperate” and “non-cooperate” the payoffs will be

Table 1 Triple helix game: *C* Cooperate, *D* Non-Cooperate

$$Players = \{University, Industry, Government\}$$

$$Actions = \{Cooperate, Non-Cooperate\}$$

$$Payoffs = \{x > y > z > m\}$$

If Government chooses *C*:

		University	
		<i>C</i>	<i>D</i>
Industry	<i>C</i>	(z, z, z)	(x, m, x)
	<i>D</i>	(m, x, x)	(m, m, x)

If Government chooses *D*:

		University	
		<i>C</i>	<i>D</i>
Industry	<i>C</i>	(x, x, m)	(x, m, m)
	<i>D</i>	(m, x, m)	(y, y, y)

determined using the game structure of prisoner’s dilemma then the formalization is the following:

$$Players = \{University, Industry, Government\} \tag{1}$$

$$Actions = \{Cooperate, Non-Cooperate\} \tag{2}$$

$$Payoffs = \{x > y > z > m\} \tag{3}$$

Table 1 shows the payments of each of the strategies chosen by each player, cooperation is considered more valuable than not cooperating because people or institutions that seek collaboration are usually highly productive (Katz and Martin 1997), especially Latin American innovative systems where research collaboration can help decrease their innovation deficit and improve the quality of their knowledge infrastructure (Cooke and Leydesdorff 2006). The optimal strategy for the three parties is to collaborate; by iterative elimination of dominated strategies, we find that C–C–C is the nash equilibrium in pure strategies. With this evidence, it can say that the triple helix game can be extended to a cooperative game; this branch of game theory analyzes situations where players cooperate to create coalitions. Formal structure is characterized by two parts: (i) player set and (ii) characteristic function that would be the function that gives input to each of the individual and collective values of each player (Osborne and Rubinstein 1994). Academic collaborations happen mostly through scientific publications; according to Mègnighèto (Mègnighèto 2018b) in counting publications, there are two methods: full counting and fractional counting; the

first one refers to when the publication is given to each co-author, and the second one is assigned proportionally to each co-author. In this paper, full counting will be used but filtered in STEM areas.

Co-authorship as collaboration synergy

Academic publications, particularly within the Triple Helix model, elucidate the intricate nuances of collaboration, and these dynamics resonate well with game theory principles. Wagner and Leydesdorff (Leydesdorff and Wagner 2008) highlight that co-authorships are not merely names on a paper; they signify genuine, strategic academic collaborations that reflect social ties and intellectual convergence. Viewing co-authorships through the lens of game theory, these alliances can be seen as coalitions—strategic moves made by institutions (or ‘players’) to maximize their joint outcomes (Melin 2000). Just as players form coalitions in-game scenarios to optimize results, institutions collaborate to leverage collective expertise, share resources, and elevate the impact of their research. This perspective reinforces the value of collaborative endeavors, emphasizing that the combined efforts of institutions often surpass what they might achieve in isolation. The nature of these coalitions, rooted in the strategic interplay of decision-making, embodies the essence of game theory, where the predicted actions of others intricately influence choices.

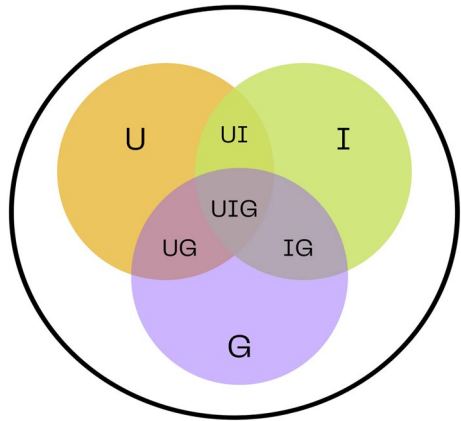
While it is true that co-authorship is sometimes criticized because certain co-authors may only lend their name without substantially contributing to the work, it is essential to underscore that our study focuses on co-authorships between institutions, not individual authors. In this context, collaboration holds more weight. Institutions’ reputations and prestige are at stake, making it more likely that the quality of contributions in co-authorship is significant. Furthermore, projects involving University–Industry–Government (U–I–G) collaborations tend to be backed by more substantial financial support, reflecting their seriousness and importance (Moon et al. 2019).

Coalitions and characteristic function

Coalitional games involve an ordered pair (\mathcal{N}, v) , where \mathcal{N} is a finite set of players denoted by $\mathcal{N} = \{1, \dots, \mathcal{N}\}$, v is a function of all subsets of \mathcal{N} then $v : 2^{\mathcal{N}} \rightarrow \mathcal{R}$ is called characteristic function and is associates with every coalition $S \subseteq \mathcal{N}$ a real number which represent value or gain of S and the number of coalitions in an n -player game is 2^n (Saad et al. 2009). Figure 1 depicts Triple Helix strategic interactions used for many authors in a different context (Mêgnigbêto 2018b; øivind Strand and Leydesdorff 2013; Zhou 2014). Thus, Fig. 1 shows the numbers of coalitions in triple helix game $2^3 = 8$, coalitions set is given by $\mathcal{C} = \{\emptyset, (U), (I), (G), (U, I), (U, G), (I, G), (U, I, G)\}$ it is made up of the empty coalition, the one-player coalition, the two-player coalition, and finally the grand coalition between all the actors involved.

The values obtained by the coalitions will depend on whether transferable utility (TU) or non-transferable utility (NTU) is used; TU games mean that the total utility of a coalition can be divided in any way between each of the actors that interact in the coalition. On the other hand, there are situations where we cannot assign coalition values to a specific value, or coalitions have restrictions on the distribution of rewards; these scenarios are called NTU games (Saad et al. 2009). In The Latin America Triple Helix game, it will be considered a game with utility transfer; then coalitions

Fig. 1 Triple Helix spheres’ contributions to Triple Helix relationships



rewards will be given by the individual and collective contributions of each actor, i.e., $UI = \text{Individual Contribution} + \text{Collective Contribution} = U + I + UI$.

So the characteristic function of the game is the following:

$$v(\mathcal{S}) = \begin{cases} v(\emptyset) = 0 \\ v(u) = U \\ v(i) = I \\ v(g) = G \\ v(ui) = U + I + UI \\ v(ug) = U + G + UG \\ v(ig) = I + G + IG \\ v(uig) = U + I + G + UIG \end{cases} \tag{4}$$

Allocation metrics

An allocation is a rule that specifies the payoff of each \mathcal{N} number of players gets when players cooperate to form coalitions. The rule is a function that allocates to every player (\mathcal{N}, v) a value that considers their individual and collective contributions (Caulier et al. 2017). In this paper, we will use the following rules: Core, Shapley Value, and Nucleolus.

Core

The core is a situation in which an agreement between \mathcal{N} only if each player obtains at least his minimum value of $v(\mathcal{S})$ within the characteristic function of the game (Gilles 2010; Shapley and Shubik 1969):

For every player $X_i \subset \mathcal{N}$

$$\sum_{i \in \mathcal{N}} X_i = v(\mathcal{N}) \tag{5}$$

and for every coalition $S \subset \mathcal{N}$

$$\sum_{i \in S} X_i \geq v(S) \tag{6}$$

According to Eqs. (5) and (6), taking into account players of the triple helix, it is considered $X_u, X_i,$ and X_g as the minimum utility that each player can accept to form a coalition:

$$C(v) = \begin{cases} X_u \geq v(u) \\ X_i \geq v(i) \\ X_g \geq v(g) \\ X_u + X_i \geq v(ui) \\ X_u + X_g \geq v(ug) \\ X_i + X_g \geq v(ig) \\ X_u + X_i + X_g = v(uiig) \end{cases} \tag{7}$$

To find a solution, two-variables inequalities are transformed to one-variable inequalities, more details (Mêgnigbêto 2018b).

$$C(v) = \begin{cases} v(u) \leq X_u \leq v(uiig) - v(ig) \\ v(i) \leq X_i \leq v(uiig) - v(ug) \\ v(g) \leq X_g \leq v(uiig) - v(ui) \\ X_u + X_i + X_g = v(uiig) \end{cases} \tag{8}$$

The core can be graphed; if it is a two-player game, it can be graphed in a Cartesian plane. If it is a three-player game, a ternary diagram could be used (Gilles 2010; Mêgnigbêto 2018b), which consists of an equilateral triangle that plots the relative points of the proportions of three members (Howarth 1996).

Shapley value

The Shapley value is the average of all marginal contributions that each player can give to different orders of coalitions and is considered the fairway to allocate the payoff of each player (Maleki et al. 2020). One of its main characteristics is unique, it always exists and has many generalizations, but the two main formulations to calculate it are the following (Shapley 1953):

Standard Formulation

$$\varphi(v) = \sum_{S \subset N: i \in S} \frac{(|S| - 1)!(n - |S|)!}{n!} \left[v(S) - v\left(\frac{S}{i}\right) \right] \tag{9}$$

Probabilistic Formulation

$$\varphi(v) = \frac{1}{n!} \sum_{p \in \gamma(2^n)} X^p \tag{10}$$

The probabilistic function Eq. (10) will be used to compute the Shapley Value, the number of permutations of the triple helix game is given by $3! = 6$ then consider an order of entrance of each permutation e.g., “U–I–G is an order, U–G–I is another order and so on”; the marginal contribution of players is computed by order of entrance in each coalition, and finally the Shapley Value will be the average of payoffs of each player and the number of permutations (Mêgnigbêto 2018b) (Table 2):

$$\varphi(v) = \begin{cases} S_u = \frac{2v(ui) + 2v(u) + v(ui) + v(ug) - 2v(ig) - v(i) - v(g)}{6} \\ S_i = \frac{2v(ui) + 2v(i) + v(ui) + v(ig) - 2v(ug) - v(u) - v(g)}{6} \\ S_g = \frac{2v(ui) + 2v(g) + v(ig) + v(ug) - 2v(ui) - v(i) - v(u)}{6} \end{cases} \quad (11)$$

Nucleolus

The nucleolus (Schmeidler 1969) is an allocation rule that makes the largest unhappiness coalition as happy as possible. At the core of a game exists payoffs distributions that are efficient and rationale for the players; these distributions are called imputations (Peters 2015):

Imputation set of a TU game (\mathcal{N}, v)

$$\mathcal{I}(\mathcal{N}, v) = \{X \in \mathbb{R}^{\mathcal{N}} \mid x(\mathcal{N}) = v(\mathcal{N}), x_i \geq v(i) \text{ for all } i \in \mathcal{N}\} \quad (12)$$

So we can measure the unhappiness of a coalition with respect to an allocation x as follows:

$$e(\mathcal{S}, X) = v(\mathcal{S}) - x(\mathcal{S}) \quad (13)$$

A greater $e(\mathcal{S}, X)$ means a more remarkable degree of “happiness” of coalition \mathcal{S} ; therefore, the Nucleolus is the only imputation in the core in which no coalition can improve its “satisfaction” without harming the happiness of another “less happy” coalition. The Nucleolus always exists and is unique (Kohlberg 1971; Schmeidler 1969). The Nucleolus does not have an analytical formula, so the solutions have to be approximated with Linear Programming (LP) using iterative approaches (Perea and Puerto 2019; Kimms and Çetiner 2012). In this paper, we will use the package “Game Theory” of the R programming language, the package has a friendly framework and robust results to calculate metrics of cooperative games (Cano-Berlanga et al. 2017; Mênigbêto 2018b).

Classification

The next step is to identify the actors of the TH innovation systems. An exhaustive investigation was carried out to find the most outstanding institutions in each country. By outstanding institutions, we refer specifically to those institutions that appear on official websites and are well-recognized in their respective countries. Our in-depth research not only focused on locating these prominent institutions but also on entities that have affiliations or connections with them. However, just remembering the institutions is not enough, as some lower-ranking institutions are not mentioned in the official channels, and it is not feasible to name each company. Therefore, we will use a text mining technique called Regular Expression (regex) to identify institutions and coalitions. In scientometrics, regex is a widely used tool when it is necessary to find patterns to extract, clean, or identify words; Cabanac (Cabanac 2014) used regex to extract eponyms from full-text articles. Xu et al. (2019) implemented a system for cleaning up regex errors in prefixes and suffixes DOIs in the WoS database. Zhao and Strotmann (2020) proposed a regex implementation to identify APA in text or Harvard-style citations. Tamada et al. (2006) has developed a regex system to extract cited references in Japanese patent documents.

Table 2 Computing the Shapley value using probabilistic equation Triple Helix Game

Order of Entrance	u	i	g	Total
i g	$v(u)$	$v(ui) - v(u)$	$v(ug) - v(u)$	$v(ug)$
u g i	$v(u)$	$v(ug) - v(ug)$	$v(ug) - v(u)$	$v(ug)$
i u g	$v(ui) - v(i)$	$v(i)$	$v(ug) - v(ui)$	$v(ug)$
i g u	$v(ug) - v(ig)$	$v(i)$	$v(ig) - v(i)$	$v(ug)$
g u i	$v(ug) - v(g)$	$v(ug) - v(ug)$	$v(g)$	$v(ug)$
g i u	$\frac{2v(ui) + 2v(u) + v(ug) - 2v(ig) - v(i) - v(g)}{6}$	$v(ig) - v(g)$	$v(g)$	$v(ug)$
Average		$\frac{2v(ui) + 2v(i) + v(ig) - 2v(ug) - v(u) - v(g)}{6}$	$\frac{2v(ug) + 2v(g) + v(ig) + v(ug) - 2v(ui) - v(i) - v(u)}{6}$	$v(ug)$

The decision to use Web of Science (WoS) as our primary data source was driven by its reputation for reliability and integrity in academic research (Li et al. 2018). WoS is renowned for its rigorous peer-review process, ensuring that the collaborations we study are significant and adhere to stringent academic standards (Archambault et al. 2009). This lends credibility to our exploration of academic coalitions, offering a solid foundation for analyzing coalition dynamics in congruence with the tenets of game theory. This choice underpins the robustness of our methodology and assures the relevance and quality of the collaborations examined.

Our objective is to identify each coalition of the triple helix sphere; Figure 2 shows the task flows to obtain the TH, starting with the extraction of information for each country from the database, then we carry out a cleaning process and separation by coalition size. The algorithm `regexTH` uses regex variables with patterns of each inventors' names; logical and boolean operations, to will identify the permutations coalition. Finally, each coalition is counted to form a consolidated number of coalitions in the TH.

Figure 3 illustrates the process of classifying entities. Initially, we conduct a primary classification using recognized institutions from each country. Table 9 (Appendix A) presents the websites we utilized to identify these recognized institutions, encompassing universities, government bodies, and list of companies traded on the stock exchanges of each country. These institutions were then employed as the initial classification layer, offering higher certainty. Subsequently, a secondary classification layer was applied, utilizing the most frequent keywords associated with each institution. To facilitate this, a string cleaning process was also implemented for the institutional data, aiming to eliminate stopwords and other non-contributory words, thereby ensuring a more robust and relevant identification. Our classification adheres strictly to these criteria; any case falling outside these parameters was excluded, reducing the likelihood of incorporating improperly classified examples.

The classification process was established as follows, in accordance with the table of main keywords (Table 10) presented in (Appendix A):

1. **University:** We utilized official sources to gather a list of universities in each country studied. These sources include government and educational websites and academic databases, among others. Additionally, we applied a filter using keywords such as 'FAC', 'UNIV', and the like, ensuring that we considered legitimate academic institutions.
2. **Government:** To pinpoint governmental affiliations, we turned to the official websites of governments from the studied countries. These sites often list their primary institutions and other affiliated entities. For this purpose, we employed keywords like 'MINIST' 'GOV', and others.
3. **Industry:** Regarding affiliations with industry, we relied on well-recognized keywords, like 'CORP', 'LTD', 'LTDA', etc. This approach also included companies listed on stock exchanges, primarily consolidated firms likely to finance research projects.

An essential factor is that the algorithm considers possible repetitions of actors in each coalition; for example, the coalition (UU), although it has two inventors, only come from an institution University, so it is considered as a U coalition, another case would be a coalition. However, it has three names viewed as an IG coalition.

We acquired scientific publication data from the Web of Science (WoS) over ten years (2010–2020). We applied filters for the selected countries and mapped the STEM fields using the scientific areas available in the WoS database. This process included all available

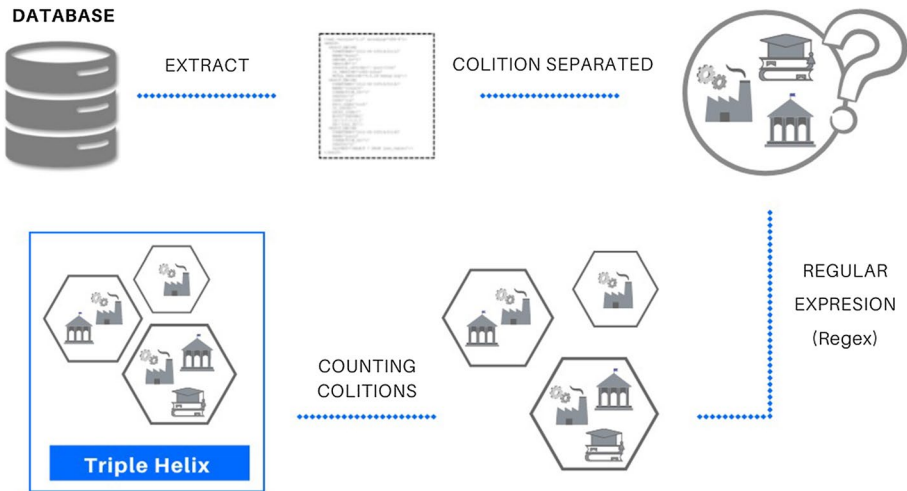


Fig. 2 Classification process: Extraction from WoS, criteria for separating actors, application of the RegexTH algorithm, and finally counting each coalition

languages and focused exclusively on scientific articles. For more detailed information, see Table 8 in Appendix A.

The pseudocode of the algorithm is as follows:

Algorithm 1 RegexTH

Input : Inventors X
 University Patterns ($U = U_{regex}$)
 Government Patterns ($G = G_{regex}$)
 Industry Patterns ($I = I_{regex}$)
 Coalitions K ($K = 7$)

Output: $U^* I^* G^* UI^* IG^* UG^* UIG^*$

- 1 **for** $X == len(1)$
 if $X == (U_{regex} OR G_{regex} OR I_{regex})$
 Compute X Output
- 2 **for** $X == len(2)$
 if $X == ((U_{regex} AND G_{regex}) OR (I_{regex} AND G_{regex}) OR (U_{regex} AND I_{regex}))$
 Compute X Output
- 3 **for** $X == len(3)$
 if $X == AND_{i=1}^{n=5} OR UIG! \# ! = UIG$ Permutations
 Compute X Output



Fig. 3 Illustration of the process of classifying actors, using both keywords and recognized keywords

Case study

Our case study considers the innovation systems of the following Latin American countries: Brazil, Mexico, Chile, and Argentina; we will use the rules of the triple helix game and compute the allocation metrics: Core, Shapley value, and Nucleolus. Bibliometric information was compiled by the number of publications filtered by STEM areas downloaded from the Web of Science in 2010–2020.

Data wrangling and characteristic function

The database treatment was enriched using the bibliometrix package (Aria and Cuccurullo 2017). The leading institutions of the triple helix in each country were identified and categorized using pattern recognition techniques. Table 3 shows the numbers of papers in STEM areas in each coalition; it was presented in percentage share to avoid absolute number biases. Table 4 shows the outputs of the characteristic function of the triple helix of each country. Figure 2 shows the publications in relative terms of each of the coalitions and the total in absolute terms for each country; it can be seen that the university has the highest participation; however, industry and government present different participations between countries (Fig. 4).

Cores and ternary diagrams

The ternary diagrams of the triple helix of each country were plotted using the “ggtern” package (Hamilton and Ferry 2018) from R programming language. Table 5 shows the Core analytical form on the triple helix of each country; Ternary diagrams in Fig. 5 labeled University at the top apex, the left one Industry, and the right one Government. Red lines correspond to the limits of X_u , blue lines to the limitations of X_i and green lines the boundaries of X_g , the intercepts of each line correspond to the core area (gray color). To paint the core surface, we drew a polygon with the intercepts, each point in the diagram equal to $X_u + X_i + X_g = 100$. Two core intercepts will always be known, and the coordinates can be easily calculated e.g., if we want to calculate the value of X_u knowing the intercepts of X_i and X_g then $1 - X_i + X_g = X_u$.

Computing shapley value and nucleolus

Shapley value and nucleolus were computed with Eqs. (11), (12), (13) and help of the “GameTheory” package (Cano-Berlanga et al. 2017) from R programming language. Table 6 shows the values of both metrics for each country:

Discussion

Main actors

The analytical form of the core shows us the individual and collective contributions of each actor Table 5. The main actor in each country is the university with an average individual and collective representation value from 65% to 98%. The second one is the government with a range from 3% to 24%, and the third is the industry having a result from 1% to 9%, which is seen very clearly in the ternary diagrams Fig. 3 where the core area tends to converge near to university apex.

Chile: where the individual contributions of industry and government are not representative, but their collective contributions to the university are considerable in their characteristic function. Chile considers universities as the benchmark for making scientific publications; therefore, government and industry seek to collaborate. The university is an actor with the most experience and autonomy to carry out high-impact scientific productions; this behavior is very similar to the static game in Table 1. Chile has had a scientific and economic collaboration agreement between CONICYT¹ and Innova Chile² since 2010, which has allowed the transfer of knowledge between private companies, government agencies, public and private universities.

Brazil: university represents participation that reaches 90%, the industry does not have a relevant weight in the individual production of scientific publications. However, its increase is notable when it collaborates with the university, but it is still the lowest percentage shared among the countries analyzed. Brazil's Governments have individual participation four times greater than Chile; however, both countries have a similar percentage share in the U–G coalition. The bond between government and science is very strong in Brazil, organizations such as CAPES³, CNPq⁴ and foundations that support research were created to develop scientific and technological advance, allowing the stability of the scientific system. Despite budget cuts of recent years, Brazil has one of the most robust U–G structures in the Latin American region.

Mexico: the university also reaches a contribution of 90%, but its scientific production drops to 65% of shared percentage compared to Brazil and Chile, industry and government shared percentage is the highest among the countries involved. It can be said that the university allows other actors to develop their own research. Government is a relevant actor in supporting scientific contributions in Mexico.

Argentina: Argentina's collaboration between University and Government is not as high as the other countries. This could be due to greater attention of private companies to collaborate with universities in scientific production, according to a study by de Moya Anegón et al. (2012) international and national companies have increased their collaboration among the most prestigious universities of Argentina in the 2007–2010 period. But according to Leydesdorff, this could also be due to a lack of incentives between these two players (Øivind Strand and Leydesdorff 2013), so the university seeks to fill those incentives by collaborating with the industry.

¹ Comisión Nacional de Investigación Científica y Tecnológica

² Institution that supports technological innovation in Chile

³ Coordenação de aperfeiçoamento de pessoal de nível superior

⁴ Conselho Nacional de Desenvolvimento Científico e Tecnológico

Table 3 Absolute and relative number of stem papers coalition counts per country from the RegexTH algorithm output

Countries	Item	U	I	G	UG	UI	IG	UIG	Total
Brazil	Number of stem papers	158,218	554	5912	43,114	11,594	876	3672	223,940
	% share	70.6520	0.2474	2.6400	19.2525	5.1773	0.3912	1.6397	100
Mexico	Number of stem papers	52,331	1649	3777	15,950	4258	395	1244	79,604
	% share	65.7392	2.0715	4.7447	20.0367	5.3490	0.4962	1.5627	100
Chile	Number of stem papers	31,527	127	289	8847	2525	61	1017	44,393
	% share	71.0180	0.2861	0.6510	19.9288	5.6878	0.1374	2.2909	100
Argentina	Number of stem papers	33995	506	2231	7517	3383	361	1257	49,186
	% share	69.1152	1.0287	4.5358	15.2828	6.8780	0.7339	2.5556	100

Table 4 Characteristic Function Latin America Triple helix Game: shows each coalition’s synergy level for one of the studied countries

	Characteristic function						
Brazil	$\left\{ \begin{array}{l} v(u) = 70.65 \\ v(i) = 0.24 \\ v(g) = 2.64 \\ v(ui) = 76.07 \\ v(ug) = 92.54 \\ v(ig) = 3.27 \\ v(uig) = 100 \end{array} \right.$	Mexico	$\left\{ \begin{array}{l} v(u) = 65.74 \\ v(i) = 2.07 \\ v(g) = 4.74 \\ v(ui) = 73.16 \\ v(ug) = 90.52 \\ v(ig) = 7.31 \\ v(uig) = 100 \end{array} \right.$	Chile	$\left\{ \begin{array}{l} v(u) = 71.02 \\ v(i) = 0.29 \\ v(g) = 0.65 \\ v(ui) = 76.99 \\ v(ug) = 91.60 \\ v(ig) = 0.0107 \\ v(uig) = 100 \end{array} \right.$	Argentina	$\left\{ \begin{array}{l} v(u) = 69.11 \\ v(i) = 1.02 \\ v(g) = 4.53 \\ v(ui) = 77.02 \\ v(ug) = 88.93 \\ v(ig) = 6.29 \\ v(uig) = 100 \end{array} \right.$

While universities play a crucial role in the innovation systems of all four countries, the involvement of government and industry varies: Brazil, Argentina, and Mexico each demonstrate high individual government participation, suggesting that certain scientific research initiatives may overlook the input of the most experienced player. The focus on isolated participation is frequently very concentrated in specific research areas, the value placed on agility often lead researchers to prefer working independently rather than seeking collaborative efforts. Collaboration, while valuable, can be time-consuming, especially when it involves organizing research teams and coordinating with subject matter experts. Additionally, the bureaucratic processes required to determine each participant’s degree of involvement can pose a significant barrier to effective teamwork and collaborative research.

If an individual player’s scientific collaboration is very low, it implies they have sufficient incentives to collaborate with other players. In the case of Chile, both government and industry choose to collaborate with universities, which is a rational behavior considering that the university is the most experienced player. It can demonstrate good synergy among the parties in agreeing on the degree of involvement and effective communication between specialists from each player.

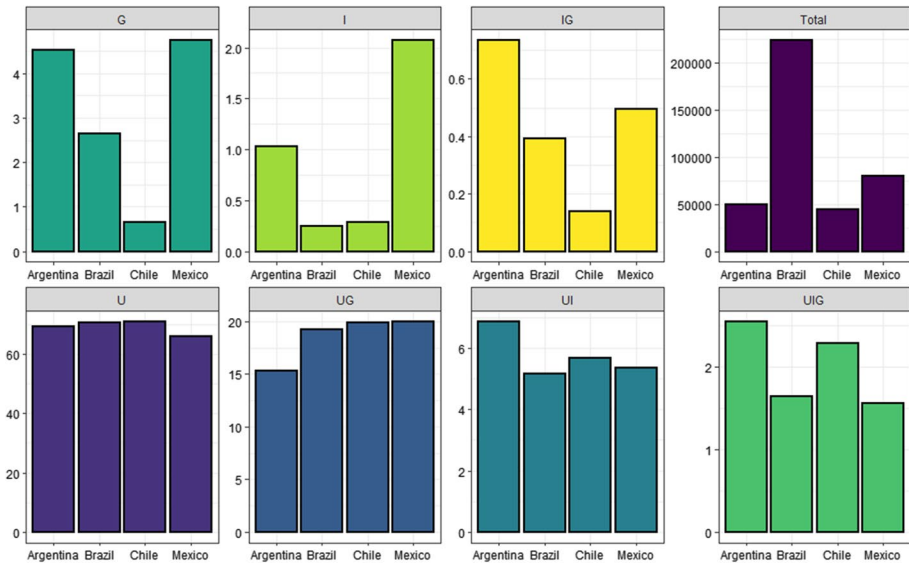


Fig. 4 Latin American Triple Helix percentage shares and total; provide a comparison of the size of each player in their innovation system. This figure is a summary of Table 3

Collaboration power and coexistence

Shapley Value output in Table 6 confirms that actors with the most considerable energy are: University, Government, and Industry, respectively. Shapley Value is a measure of the marginal contribution that an actor will make when forming a coalition. The university innovation system of Chile and Brazil are the ones with the greatest power to lead coalitions. On the other hand, the government in Mexico has the highest value among the countries studied, which shows the critical weight of the Mexican innovation system. Lastly, industries in Argentina and Mexico have more power to collaborate than in any other countries studied (see Table 7).

Nucleolus output in Table 6 shows that the most relevant actors are also university, government, and industry. The nucleolus seeks the distribution that produces the most excellent possible satisfaction for the least happy coalition. Table 6 shows that the government has to give consent to reach a satisfactory imputation to satisfy the industry. However, we observe that the values of the nucleolus of Chile in items I and G are almost equal; this happens because the difference between their contribution is tiny, see in Table 3. Thus, the nucleolus is not a “Robin hood” that always gives to the most disadvantaged; the actors make consents to create “coexistence” between those involved. The value of the nucleolus depends a lot on the payoffs of each coalition, very immediate payoffs between coalitions will tend to produce nucleolus values that are also almost similar.

Table 5 The Core Analytical Form from the Latin America Triple Helix Game shows the range of payoffs that a coalition is willing to consider when negotiating an agreement.

Core Analytical Form		
Brazil	$\left\{ \begin{array}{l} 70.65 \leq X_u \leq 96.72 \\ 0.24 \leq X_j \leq 7.45 \\ 2.64 \leq X_g \leq 23.92 \\ X_u + X_j + X_g = 100 \end{array} \right.$	Mexico
	$\left\{ \begin{array}{l} 65.74 \leq X_u \leq 92.69 \\ 2.07 \leq X_j \leq 9.48 \\ 4.74 \leq X_g \leq 26.84 \\ X_u + X_j + X_g = 100 \end{array} \right.$	Chile
	$\left\{ \begin{array}{l} 71.02 \leq X_u \leq 98.93 \\ 0.29 \leq X_j \leq 8.40 \\ 0.65 \leq X_g \leq 23.10 \\ X_u + X_j + X_g = 100 \end{array} \right.$	Argentina
	$\left\{ \begin{array}{l} 69.11 \leq X_u \leq 93.70 \\ 1.02 \leq X_j \leq 11.06 \\ 4.53 \leq X_g \leq 22.97 \\ X_u + X_j + X_g = 100 \end{array} \right.$	

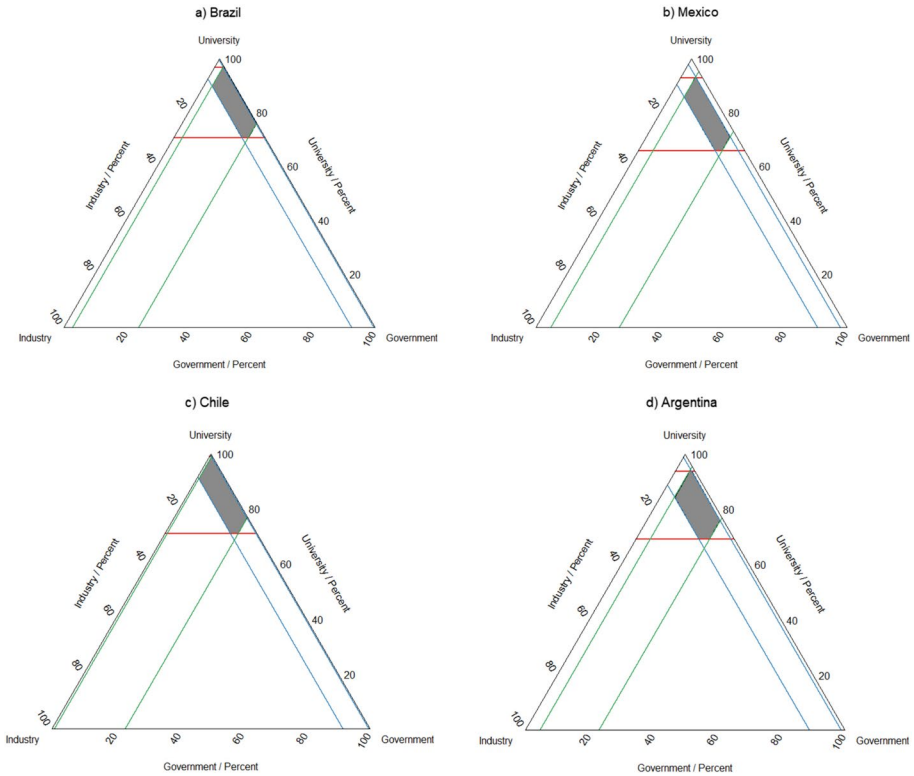


Fig. 5 Ternary Diagram Latin American Triple Helix Game: The gray area is a visual representation of the core innovation system of each country, making it easier to compare individual and collective participation

Table 6 Shapley value and Nucleolus: Displays the allocation under fairway and coexistence criteria that can be applied in different contexts to reach an agreement

	Brazil		Mexico		Chile		Argentina	
	Shapley Value	Nucleolus	Shapley Value	Nucleolus	Shapley Value	Nucleolus	Shapley Value	Nucleolus
U	83.41	89.90	78.95	85.78	84.59	90.95	81.00	84.40
I	3.57	3.85	5.515	5.775	3.96	4.345	5.64	6.04
G	13.01	6.25	15.53	8.445	11.44	4.705	13.35	9.55

Adjustment

Variations between countries in scientific publications reflect differences in size and economic structure. Latin America is a very diverse region, therefore it is vital to adjust scientific production in order to have a fairer system innovation comparison.

Number of publications per 100,000 inhabitants is represented in Fig. 6 by blue bars; Chile (448), whose population is far lower than other countries, at approximately 19.2

Table 7 Rankings of Latin American countries in the Triple Helix Game using two distinct game-theoretic evaluation criteria: the Shapley Value and the Nucleolus

Ranking						
Shapley Value	U	Chile	Brazil	Argentina	Mexico	
	I	Argentina	Mexico	Chile	Brazil	
	G	Mexico	Argentina	Brazil	Chile	
Nucleolus	U	Chile	Brazil	Mexico	Argentina	
	I	Argentina	Mexico	Chile	Brazil	
	G	Argentina	Mexico	Brazil	Chile	

Depending on the chosen criteria, the significance of the players 'U,' 'I,' and 'G' can shift, illustrating the dynamic importance of each country within the framework

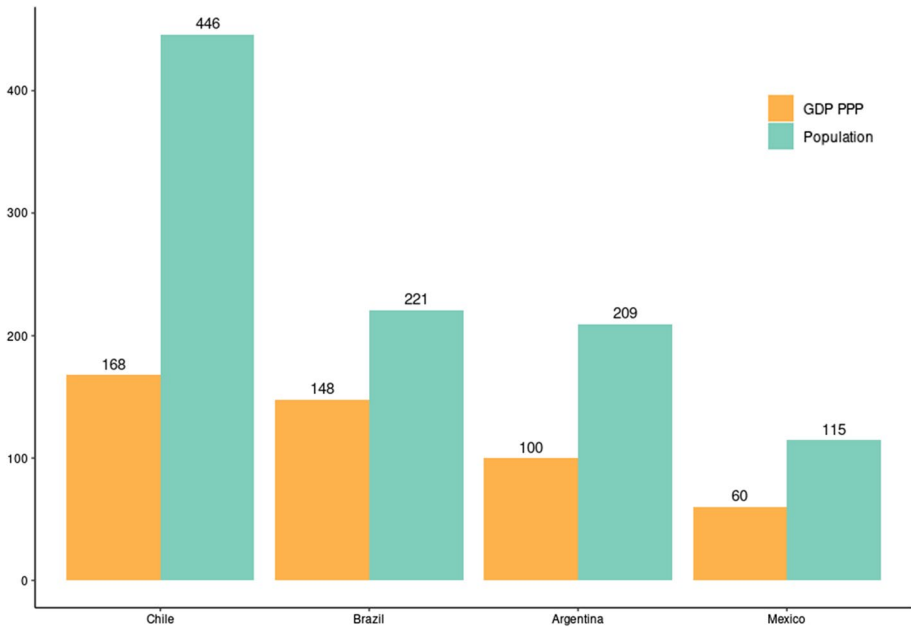


Fig. 6 Comparative analysis of paper outputs adjusted by GDP PPP (Purchasing Power Parity) and population for Latin American Game. The chart illustrates the adjusted paper counts, offering insights into the research productivity relative to each country’s economic and demographic factors

million in 2020 had almost a 1/2 ratio with Brazil, among other countries, this ratio ranged from just over 221 to about 115 publications: Brazil (221), Argentina (209) and Mexico (115). Economic activity is somewhat difficult to compare due to its dynamic characteristics, it is essential to adjust the size of the economy with the purchasing power; GDP PPP adjustment considers the number of scientific publications adapted as the purchasing power that a country currency has to acquire benefits and services without considering inflation and exchange taxes. GDP PPP adjustment is represented in Fig. 5 by yellow bars; With 168 publications per unit of USD 1,000 million GDP PPP, Chile continued to be the country that published the most articles. Still, its difference with the other countries was significantly reduced compared to the population adjustment. This is mainly because Chile has a

high cost of living compared to Brazil (148), a federal country where each state can have different living standards. In Chile, purchasing power is more homogeneous in its cities. Argentina (100) and Mexico (60) remain the same positions.

According to the World Bank statistics (World Bank Statistics 2021), Chile has an R & D expenditure of 0.356% percent of GDP (2017), Brazil 1.16% (2018), Argentina 0.494% (2018), and Mexico 0.313% (2018). Although Chile does not have high spending on R & D, adjusted for population and economic factors, Chile has the best performance. The economic policies for the increase of R & D are essential for innovative development. However, there is also a debate if those same resources are being distributed in the best way to produce more quality research.

Most of the scientific indicators come from scientific journals sites, and despite papers having precise information from search engines, publications still do not have a centralized organization that reports scientific indicators that allow academic and private institutions to assess the results of innovation policies. We consider publications should be adjusted by country due to the heterogeneity of financing policies for the scientific community. Patent metrics have developed this idea further, and every year the World Intellectual Property Organization (WIPO) publishes the World Intellectual Property Indicators (World Intellectual Property Indicators 2021), which significantly facilitates the comparison of innovation systems.

Conclusions

The triple helix can be modeled from a game theory perspective using both cooperative and non-cooperative games. In non-cooperative games, we show that in pure strategies using the structure of the prisoner's dilemma, the Nash equilibrium occurred in the cooperation strategy; in real life, cooperation is a very probable and realistic scenario. Therefore, we can conclude that the triple helix game can be expanded to a cooperative game to study and understand the influence of each player in an innovation system.

We computed game theory allocation metrics such as Core, Shapley Value, and Nucleolus. Our findings reveal that the three groups differ mainly by the percentage of individual and collective participation of each actor. The value of Shapley and the nucleolus showed that the most powerful actors are: University, Industry, and government, respectively. Shapley Value considers probabilities and individual and collective contributions to form coalitions, while the nucleolus considers the excesses of each coalition; therefore, it is highly dependent on the payoffs of the coalitions.

Our research reveals varying collaboration patterns among universities, governments, and industries. While universities play a crucial role in all these countries, the degree of government participation varies. Governments take a more individualized approach to research activities in Brazil, Argentina, and Mexico, resulting in focused but isolated efforts. In contrast, Chile demonstrates a more unified approach, with substantial engagement from both government and industry alongside universities. This distinction in collaboration models highlights the varied strategies for scientific collaboration and resource distribution in these Latin American nations.

While our study sheds light on the dynamics of collaboration through co-authorship, it's crucial to acknowledge co-authorship as a potential limitation. Solely relying on this metric might only capture part of the spectrum of collaborative endeavors. Future studies could benefit from incorporating diverse metrics to garner a more comprehensive understanding of the cooperative landscape.

Utilizing a single database (WoS) may present a limitation in our study. Other databases such as Scopus, Dimensions, and Scielo offer alternative repositories of scientific papers, which could lead to variations in the number of publications retrieved. Future research may investigate the impact of using different databases and how this choice influences the outcomes. Such analysis would provide a more comprehensive understanding of data variability across multiple scientific information sources.

Future studies may also consider indicators such as citations or patents, revealing the exploitation of knowledge with products or companies' formation. It is interesting to explore Latin American further to provide evidence of the behavior of this area in terms of innovation in the triple helix, especially with countries that are emerging and competing in technological innovation, such as Costa Rica or Uruguay. It is vitally important to know the innovative research metrics in Latin America to compare with other regions such as Europe or Asia, allowing us to know the advance or setback in this region where scientific studies related to innovation are scarce.

Appendix A. Tables

See Tables [8](#), [9](#), [10](#).

Table 8 Keywords searching in the WoS Database

Filter key	Values
CU	Brazil Argentina Chile Mexico
WC	MATHEMATICS AGRONOMY MATHEMATICS APPLIED MATERIALS SCIENCE MULTIDISCIPLINARY MECHANICS PHARMACOLOGY PHARMACY MEDICINE RESEARCH EXPERIMENTAL ENGINEERING ENVIRONMENTAL NANOSCIENCE NANOTECHNOLOGY CHEMISTRY PHYSICAL WATER RESOURCES NEUROSCIENCES PHYSICS PARTICLES FIELDS ENGINEERING MECHANICAL PARASITOLOGY AGRICULTURAL ENGINEERING ENGINEERING CIVIL FOOD SCIENCE TECHNOLOGY ENVIRONMENTAL SCIENCES PHYSICS NUCLEAR PHYSICS APPLIED OR THERMODYNAMICS BIOLOGY COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS BIOTECHNOLOGY APPLIED MICROBIOLOGY PHYSICS ATOMIC MOLECULAR CHEMICAL ENGINEERING BIOMEDICAL ASTRONOMY ASTROPHYSICS ENERGY FUELS NUCLEAR SCIENCE TECHNOLOGY ENGINEERING ELECTRICAL BIOPHYSICS INSTRUMENTS INSTRUMENTATION MICROBIOLOGY PHYSICS MATHEMATICAL CHEMISTRY APPLIED ENGINEERING CHEMICAL METALLURGY METALLURGICAL ENGINEERING PHYSICS CONDENSED MATTER
DT	Articles

Table 9 Official links displaying the list of universities, industries, and governmental institutions for each country

Countries	Websites
Brazil	U-Link G-Link I-Link
Chile	U-Link G-Link I-Link
Argentina	U-Link G-Link I-Link
Mexico	U-Link G-Link I-Link

Table 10 List of most frequent main keywords for each player in the Triple Helix

Player	Main Keywords
U	UNIV, FAC, POLI
I	CO, CORP, LTDA, INC, LTD, GRP, ENT, SVC, CIA, MGMT, SOL, HLDG, SA, EMPS
G	MINIST, GOB, GOV, DEPT, NATIO, AGCY, OFCC, COMM, AUTH, ADMIN, CNCL, SEC

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Archambault, E., Campbell, D., Gingras, Y., & Larivière, V. (2009). Comparing bibliometric statistics obtained from the web of science and scopus. *Journal of the American Society for Information Science and Technology*, *60*(7), 1320–1326. <https://doi.org/10.1002/asi.21062>

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An r-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. <https://doi.org/10.1016/j.joi.2017.08.007>

Cabanac, G. (2014). Extracting and quantifying eponyms in full-text articles. *Scientometrics*, *98*(3), 1631–1645. <https://doi.org/10.1007/s11192-013-1091-8>

Cai, Y., & Amaral, M. (2021). The triple helix model and the future of innovation: A reflection on the triple helix research agenda. *Triple Helix*, *8*, 217–229. <https://doi.org/10.1163/21971927-12340004>

Cai, Y., & Etkowitz, H. (2020). Theorizing the triple helix model: Past, present, and future. *Triple Helix*, *6*, 1–38. <https://doi.org/10.1163/21971927-bja10003>

Callens, C., & Verhoest, K. (2023). Unlocking the process of collaborative innovation - combining mechanisms of divergence and convergence. *Public Management Review*. <https://doi.org/10.1080/14719037.2023.2171096>

Cano-Berlanga, S., Giménez-Gómez, J.-M., & Vilella, C. (2017). Enjoying cooperative games: The r package gametheory. *Applied Mathematics and Computation*, *305*, 381–393. <https://doi.org/10.1016/j.amc.2017.02.010>

Caulier, J.-F., Skoda, A., & Tanimura, E. (2017). Allocation rules for networks inspired by cooperative game-theory. *Revue d'économie politique*, *127*(4), 517–558.

Chatain, O. (2016). *Cooperative and Non-cooperative Game Theory*, Palgrave Macmillan UK, London, pp. 1–3. https://doi.org/10.1057/978-1-349-94848-2_468-1.

- Cooke, P., & Leydesdorff, L. (2006). Regional development in the knowledge-based economy: The construction of advantage. *The Journal of Technology Transfer*, 31(1), 5–15. <https://doi.org/10.1007/s10961-005-5009-3>
- de Moya Anegón, F., Chinchilla-Rodríguez, Z., Corera-Álvarez, E., & Díaz-Pérez, M. (2012). 'Estudio de la producción científica y tecnológica en colaboración universidad-empresa en iberoamérica'.
- Dubina, I. N. (2015). A basic formalization of the interaction of the key stakeholders of an innovation ecosystem. *Mathematical Economics*, 11(18), 33–42.
- Etzkowit, H., & Leydesdorff, L. (1998). *Universities and the global knowledge economy: A triple helix of university- industry relations*. Pinter Pub Ltd.
- Fidanovski, F., Simeonovski, K., Kaftandzieva, T., Ranga, M., Dana, L.-P., Davidovic, M., Ziolo, M., & Sergi, B. S. (2022). The triple helix in developed countries: when knowledge meets innovation? *Heliyon*, 8(8), e10168. <https://doi.org/10.1016/j.heliyon.2022.e10168>
- Gilles, R. P. (2010). *The Cooperative Game Theory of Networks and Hierarchies*, number 978-3-642-05282-8 in 'Theory and Decision Library C'. Springer. <https://doi.org/10.1007/978-3-642-05282-8>
- Hamilton, N. E., & Ferry, M. (2018). Ternary diagrams using ggplot2. *Journal of Statistical Software, Code Snippets*, 87(3), 1–17. <https://doi.org/10.18637/jss.v087.c03>
- Howarth, R. J. (1996). Sources for a history of the ternary diagram. *The British Journal for the History of Science*, 29(3), 337–356. <https://doi.org/10.1017/S000708740003449X>
- Ito, S., & Watanabe, T. (2021). Multilevel analysis of research management professionals and external funding at universities: Empirical evidence from japan. *Science and Public Policy*. <https://doi.org/10.1093/scipol/scaa074>
- Jovanović, M., Savić, G., Cai, Y., & Levi-Jakšić, M. (2022). Towards a triple helix based efficiency index of innovation systems. *Scientometrics*, 127(5), 2577–2609. <https://doi.org/10.1007/s11192-022-04304-x>
- Katz, J., & Martin, B. R. (1997). What is research collaboration? *Research Policy*, 26(1), 1–18. [https://doi.org/10.1016/S0048-7333\(96\)00917-1](https://doi.org/10.1016/S0048-7333(96)00917-1)
- Kimms, A., & Çetiner, D. (2012). Approximate nucleolus-based revenue sharing in airline alliances. *European Journal of Operational Research*, 220(2), 510–521. <https://doi.org/10.1016/j.ejor.2012.01.057>
- Kohlberg, E. (1971). On the nucleolus of a characteristic function game. *SIAM Journal on Applied Mathematics*, 20(1), 62–66.
- Kruss, G., & Visser, M. (2017). Putting university-industry interaction into perspective: a differentiated view from inside south african universities. *The Journal of Technology Transfer*, 42(4), 884–908. <https://doi.org/10.1007/s10961-016-9548-6>
- Leydesdorff, L. (2013). An evaluation of impacts in “nanoscience & nanotechnology”: steps towards standards for citation analysis. *Scientometrics*, 94(1), 35–55. <https://doi.org/10.1007/s11192-012-0750-5>
- Leydesdorff, L., & Meyer, M. (2003). The triple helix of university-industry-government relations. *Scientometrics*, 58(2), 191–203. <https://doi.org/10.1023/A:1026276308287>
- Leydesdorff, L., & Park, H. W. (2014). Can synergy in triple helix relations be quantified? a review of the development of the triple helix indicator. *Triple Helix*, 1(1), 4. <https://doi.org/10.1186/s40604-014-0004-z>
- Leydesdorff, L., & Wagner, C. S. (2008). International collaboration in science and the formation of a core group. *Journal of Informetrics*, 2(4), 317–325. <https://doi.org/10.1016/j.joi.2008.07.003>
- Li, K., Rollins, J., & Yan, E. (2018). Web of science use in published research and review papers 1997–2017: a selective, dynamic, cross-domain, content-based analysis. *Scientometrics*, 115(1), 1–20. <https://doi.org/10.1007/s11192-017-2622-5>
- Maleki, S., Rahwan, T., Ghosh, S., Malibari, A., Alghazzawi, D., Rogers, A., Beigy, H., & Jennings, N. R. (2020). The shapley value for a fair division of group discounts for coordinating cooling loads. *PLOS ONE*, 15(1), 1–28. <https://doi.org/10.1371/journal.pone.0227049>
- Mêgnigbêto, E. (2018). Measuring synergy within a triple helix innovation system using game theory: cases of some developed and emerging countries. *Triple Helix*, 5(1), 6. <https://doi.org/10.1186/s40604-018-0054-8>
- Mêgnigbêto, E. (2018). Modelling the triple helix of university-industry-government relationships with game theory: Core, shapley value and nucleolus as indicators of synergy within an innovation system. *Journal of Informetrics*, 12(4), 1118–1132. <https://doi.org/10.1016/j.joi.2018.09.005>
- Melin, G. (2000). Pragmatism and self-organization: Research collaboration on the individual level. *Research Policy*, 29(1), 31–40. [https://doi.org/10.1016/S0048-7333\(99\)00031-1](https://doi.org/10.1016/S0048-7333(99)00031-1)
- Meyer, M., Grant, K., Morlacchi, P., & Weckowska, D. (2014). Triple helix indicators as an emergent area of enquiry: a bibliometric perspective. *Scientometrics*, 99(1), 151–174. <https://doi.org/10.1007/s11192-013-1103-8>

- Meyer, M., Siniläinen, T., & Utecht, J. T. (2003). Towards hybrid triple helix indicators: A study of university-related patents and a survey of academic inventors. *Scientometrics*, 58(2), 321–350. <https://doi.org/10.1023/A:1026240727851>
- Moon, H., Mariadoss, B. J., & Johnson, J. L. (2019). Collaboration with higher education institutions for successful firm innovation. *Journal of Business Research*, 99, 534–541. <https://doi.org/10.1016/j.jbusres.2017.09.033>
- OECD, Kärkkäinen, K., & Vincent-Lancrin, S. (2013). ‘Sparking innovation in stem education with technology and collaboration’, *Centre for Educational Research and Innovation*.
- Osborne, M. J., & Rubinstein, A. (1994). *A Course in Game Theory*, Vol. 1 of *MIT Press Books*, The MIT Press.
- Paswan, J., Singh, V. K., Karmakar, M., & Singh, P. (2022). Does university-industry-government collaboration in research gets higher citation and altmetric impact? a case study from india. *Scientometrics*, 127(11), 6063–6082. <https://doi.org/10.1007/s11192-022-04508-1>
- Patra, S. K., & Muchie, M. (2018). Research and innovation in south african universities: from the triple helix’s perspective. *Scientometrics*, 116(1), 51–76. <https://doi.org/10.1007/s11192-018-2764-0>
- Pece, A. M., Simona, O. E. O., & Salisteanu, F. (2015). Innovation and economic growth: An empirical analysis for cee countries. *Procedia Economics and Finance*, 26, 461–467. [https://doi.org/10.1016/S2212-5671\(15\)00874-6](https://doi.org/10.1016/S2212-5671(15)00874-6)
- Perc, M. (2010). Growth and structure of slovenia’s scientific collaboration network. *Journal of Informetrics*, 4(4), 475–482. <https://doi.org/10.1016/j.joi.2010.04.003>
- Perea, F., & Puerto, J. (2019). A heuristic procedure for computing the nucleolus. *Computers Operations Research*, 112, 104764. <https://doi.org/10.1016/j.cor.2019.104764>
- Peters, H. (2015). The Nucleolus, in ‘Game Theory’. *Springer Texts in Business and Economics*, Springer, chapter, 19, 343–359. <https://doi.org/10.1007/978-3-662-46950-7>
- Popadiuk, S., & Choo, C. W. (2006). Innovation and knowledge creation: How are these concepts related? *International Journal of Information Management*, 26(4), 302–312. <https://doi.org/10.1016/j.ijinfomgt.2006.03.011>
- Saad, W., Han, Z., Debbah, M., Hjørungnes, A., & Basar, T. (2009). Coalitional game theory for communication networks. *IEEE Signal Processing Magazine*, 26(5), 77–97. <https://doi.org/10.1109/MSP.2009.0000000>
- Schmeidler, D. (1969). The nucleolus of a characteristic function game. *SIAM Journal on Applied Mathematics*, 17(6), 1163–1170.
- Shapley, L. S. (1953). *17. A Value for n-Person Games*, Princeton University Press, Princeton, pp. 307–318. <https://doi.org/10.1515/9781400881970-018>.
- Shapley, L. S., & Shubik, M. (1969). Pure competition, coalitional power, and fair division. *International Economic Review*, 10(3), 337–362. <https://doi.org/10.2307/2525647>
- Skoric, M. M. (2014). The implications of big data for developing and transitional economies: Extending the triple helix? *Scientometrics*, 99(1), 175–186. <https://doi.org/10.1007/s11192-013-1106-5>
- Sunahara, A. S., Perc, M., & Ribeiro, H. V. (2021). Association between productivity and journal impact across disciplines and career age. *Physical Review Research*, 3, 033158. <https://doi.org/10.1103/PhysRevResearch.3.033158>
- Sutrisna, M., Tjia, D., & Wu, P. (2021). Developing a predictive model of construction industry-university research collaboration. *Construction Innovation*, 21(4), 761–781. <https://doi.org/10.1108/CI-11-2019-0129>
- Tamada, S., Naito, Y., Kodama, F., Gemba, K., & Suzuki, J. (2006). Significant difference of dependence upon scientific knowledge among different technologies. *Scientometrics*, 68(2), 289–302. <https://doi.org/10.1007/s11192-006-0112-2>
- Timme, N., Alford, W., Flecker, B., & Beggs, J. M. (2014). Synergy, redundancy, and multivariate information measures: an experimentalist’s perspective. *Journal of Computational Neuroscience*, 36(2), 119–140. <https://doi.org/10.1007/s10827-013-0458-4>
- Tukoff-Guimarães, Y. B., Kniess, C. T., Renato, R. Silva., & Ruiz, M. (2021). Patents valuation in core innovation: case study of a Brazilian public university. *INMR - Innovation amp Management Review*, 18(1), 34–50. <https://doi.org/10.1108/INMR-03-2019-0027>
- Vesperi, W. (2017). The conflict in the academic spinoff: the game theory approach. *International Journal of Research, Innovation and Commercialisation*, 1(2), 191–204. <https://doi.org/10.1504/IJRIC.2017.091117>
- Von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior*. Princeton University Press.
- World Bank Statistics (2021). <https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=AR-BR-US-MX>.

World Intellectual Property Indicators (2021).

- Xu, H., & Liu, F. (2017). Measuring the efficiency of education and technology via dea approach: Implications on national development. *Social Sciences*. <https://doi.org/10.3390/socsci6040136>
- Xu, S., Hao, L., An, X., Zhai, D., & Pang, H. (2019). Types of errors of cited references in web of science with a cleaning method. *Scientometrics*, 120(3), 1427–1437. <https://doi.org/10.1007/s11192-019-03162-4>
- Zhang, Y., Chen, K., & Fu, X. (2019). Scientific effects of triple helix interactions among research institutes, industries and universities. *Technovation*, 86–87, 33–47. <https://doi.org/10.1016/j.technovation.2019.05.003>
- Zhao, D., & Strotmann, A. (2020). Telescopic and panoramic views of library and information science research 2011–2018: a comparison of four weighting schemes for author co-citation analysis. *Scientometrics*, 124(1), 255–270. <https://doi.org/10.1007/s11192-020-03462-0>
- Zhou, C. (2014). Four dimensions to observe a triple helix: invention of ‘cored model’ and differentiation of institutional and functional spheres. *Triple Helix*, 1(1), 11. <https://doi.org/10.1186/s40604-014-0011-0>
- Zhuang, T., Zhao, S., Zheng, M., & Chu, J. (2021). Triple helix relationship research on China’s regional university-industry-government collaborative innovation: Based on provincial patent data. *Growth and Change*, 52(3), 1361–1386. <https://doi.org/10.1111/grow.12490>
- Oivind, S., & Leydesdorff, L. (2013). Where is synergy indicated in the Norwegian innovation system? triple-helix relations among technology, organization, and geography. *Technological Forecasting and Social Change*, 80(3), 471–484. <https://doi.org/10.1016/j.techfore.2012.08.010>

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