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Contributions of Brazilian universities to technological innovation: a multivariate exploratory analysis

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ABSTRACT

The purpose of this work is to use a quantitative approach, based on a multivariate exploratory technique known as Exploratory Factor Analysis (EFA), to characterize the dynamic behavior of Brazilian public universities relevant to technological innovation in the context of the Triple Helix (TH). Data from 76 observable variables, between the years 2008 and 2015, were included in the analysis. The EFA results, based on statistical procedures that took into account official data, reduced the number of variables, revealing six (6) latent factors according to Pearson's correlation, representing almost 99% of the data variance. This dimensionality reduction shows that internal characteristics of institutions and interactions with other TH actors (industry and government) are intrinsically intertwined and can be mapped. The interdependencies of the factors promoted the understanding that Brazilian public universities act independently and interdependently to foster the cooperation necessary for technological innovation. The interdependencies, when analyzed in the light of TH, allowed the construction of a framework that made it possible to identify the particularities of the Brazilian case and to compare them with the reality of other countries, such as Malaysia, Indonesia, Germany, Thailand, Poland and the United States. In this way, it became possible to identify gaps in Brazil that, if properly explored, will be opportunities for regional and national economic and social development. Specifically for universities, it was noted that the contribution of these institutions to the technological innovation process can be more proactive and aligned with TH.

KEYWORDS: Technological Innovation. Triple Helix. Universities. Exploratory Factor Analysis.

INTRODUCTION

The role of institutional actors such as universities, industry, and governments in fostering technological innovation has been highlighted in the literature on national innovation systems (FREEMAN, 1987; LUNDVALL, 1992; NELSON, 1993; EDQUIST, 1997), as well as in the Triple Helix (TH) model (ETZKOWITZ; LEYDESDORFF, 1997; ETZKOWITZ, 2013; ETZKOWITZ; ZHOU, 2017). Both theoretical approaches emphasize that certain factors, actors and the nature of interactions, as well as the interdependence between institutions, are important for any national economic growth.

Given that science goes through continuous redefinition of its boundaries and endless transpositions, new visions have emerged that place the university at the center of debates on economic and social growth and development. In this context, interacting with other actors to advance technology, Universities are increasingly beginning to assume a broader and more relevant role not only in this relationship, but also in the society in which they are inserted (MIKOSZ *et al.*, 2018; DE OLIVEIRA *et al.*, 2022; GRAEF *et al.*, 2022; ANDRADE *et al.*, 2023; SAKASHITA *et al.*, 2023).

This work aims to use a quantitative approach, based on a multivariate exploratory technique known as factor analysis (FA), to characterize the dynamic behavior of the university relevant to technological innovation in the TH context. Briefly, FA describes the variability among observed and correlated variables in terms of a potentially reduced number of unobserved variables called factors. Our goal is to understand if there are latent factors that explain the relationship between observable variables. Observable variables are those that we can measure. Latent factors (called factors) are a phenomenon that we cannot measure directly, but that we can infer from the relationship between observable variables.

There are two types of FA, Confirmatory Factor Analysis (CFA) and Exploratory Factor Analysis (EFA). CFA is a procedure that is used to test how well the observable variables represent the number of previously established constructs. In CFA, researchers can specify the number of latent factors (representing the previously established constructs) needed in the data and which observable variables are related to which latent factor. EFA explores the database and provides information about the number of latent factors needed to represent the data. In EFA, all observable variables are related to each latent factor.

In the TH literature, Mendoza *et al.* (2020) and Muhamad *et al.* (2021), have used both EFA and CFA; while Bieliński and Tomczyńska (2019), Fitriani *et al.* (2019), Ueasangkomsate and Jangkot (2019), and Lerman *et al.* (2021) used only CFA. These studies used the Likert scale or statistics from other qualitative scales as input to the quantitative analysis, which Fávero and Belfiore (2019) suggest should be avoided.

We intend to describe a phenomenon without the intention of testing previously established constructs. Thus, in contrast to the works cited above, we have adopted the EFA approach. Another difference can be noticed between this research and the others mentioned is that here we use only quantitative observable variables, avoiding the Likert scale. The choice of the EFA statistical technique was also due to its effectiveness in simplifying complex databases, thus allowing the characterization of their underlying dynamic behavior (HAIR *et al.*, 2019; FÁVERO; BELFIORE, 2019). EFA groups variables, thus reducing the complexity of observable variables to a few latent factors, which strongly contributes to dimensionality reduction, one of the main approaches of Machine Learning (ML).

This research sheds light on the contributions of Brazilian public universities to technological innovation, while understanding that these institutions do not act in isolation but are part of an ecosystem that involves other actors. For this task, data from 76 observable variables were considered, between the years 2008 and 2015. These include relevant aspects about the contributions of Brazilian public universities to technological innovation, taking into account their specificities as institutions that work in the process, but that are not directly responsible for the innovation itself. Thus, the observable variables describe faculty; students; research environment; publication of papers; patents filed and granted; interactions between universities and government; and interactions between universities and industry (Table 1).

Eight (8) Brazilian public universities were considered for this purpose: São Paulo State University (*Universidade Estadual Paulista "Júlio de Mesquita Filho" - Unesp*); State University of Campinas (*Universidade Estadual de Campinas - Unicamp*); Federal University of Rio Grande do Sul (*Universidade Federal do Rio Grande do Sul - UFRGS*); Federal University of São Carlos (*Universidade Federal de São Carlos - UFSCar*); Federal University of Viçosa (*Universidade Federal de Viçosa - UFV*); Federal University of Paraná (*Universidade Federal do Paraná - UFPR*); Federal University of Bahia (*Universidade Federal da Bahia - UFBA*); Federal University of Pernambuco (*Universidade Federal de Pernambuco - UFPE*). These universities are from three (3) major Brazilian regions: four (4) from the Southeast (Unesp, Unicamp, UFV and UFSCar), two (2) from the South (UFRGS and UFPR) and two (2) from the Northeast (UFBA and UFPE). It was not possible to collect data from other Brazilian institutions and regions due to an absolute lack of data.

BIBLIOGRAPHIC REVIEW

A brief bibliographic review is presented, regarding TH and FA from the Brazilian academic context.

TRIPLE HELIX

In the 20th century, the understanding of the potential contributions of universities to society, both in terms of generating and increasing stocks of knowledge, human capital, technologies and other intellectual resources, expanded. This led to the effective involvement of professors and researchers in entrepreneurial activities and their effective involvement in entrepreneurial and innovative activities, using the case of the United States as a model (GRAEF *et al.*, 2022; ANDRADE *et al.*, 2023; RIBEIRO; NAGANO, 2023; SAKASHITA *et al.*, 2023).

The TH models focus on the contribution of key actors to the development of regional and national innovation: academia (universities and research institutes), industry (business actors, companies, industries, enterprises), and government. The TH provides perspectives on how knowledge is transferred among the stakeholders to create value in the innovation system (LERMAN *et al.*, 2021). This approach describes how an innovation emerges from a balanced, reciprocal and continuous relationship between academia, industry and government and a model of transformation processes between these three (3) actors (FITRIANI *et al.*, 2019).

The TH model approach is based on the understanding that knowledge develops dynamically, both within organizations and across institutional boundaries. Thus, the generation of technology and subsequent innovation occurs through knowledge produced and exploited by institutional arrangements (ETZKOWITZ; LEYDESDORFF, 1997; ETZKOWITZ, 2013; ETZKOWITZ; ZHOU, 2017). With increasing strategic interactions between academia, industry, and government, the three helixes are being transformed not only internally, but also through the mutual influence of the three main actors (DALMARCO, *et al.*, 2018).

TH argues that it is possible for an institutional sphere to play multiple roles without degrading or compromising its original role (ETZKOWITZ, 2013; ETZKOWITZ; ZHOU, 2017). The interactions are supposed to be dynamic and each actor synergistically assumes different roles and according to different needs, based on the hybridization of their nature (hybrid organizations), for example, the company that conducts research, the university undertakings, the government that invests and promotes interactions (GRAEF *et al.*, 2022; SAKASHITA *et al.*, 2023).

As a result, universities in the TH model adopt overlapping institutional logics. The social logic responds to the range of societal expectations of higher education (e.g., education and training, service to society, and the production, preservation, and dissemination of knowledge for the public good), and the industrial logic (economic) responds to the expectations of higher education for regional and national economic growth and global competitiveness (MENDOZA *et al.*, 2020).

This expansion of roles, according to the TH, leads to a greater possibility of action and a consequent rapprochement of university teachers and students with the productive sectors, a driving force for regional and national development through technology transfer (MIKOSZ *et al.*, 2018; ANDRADE *et al.*, 2023; SAKASHITA *et al.*, 2023). The immediate impact is seen in the process of technology transfer of academic discoveries, which used to take generations, now takes place throughout the professional life of its inventors, giving them the opportunity to participate in both the research process and the technological innovation process (ETZKOWITZ; ZHOU, 2017).

The latest TH thesis is that universities are no longer playing a secondary, albeit important, role in the technological innovation process as providers of higher education and research, but are assuming a primary role as inducers of new businesses. In this sense, universities are becoming institutions that combine teaching and research with activities aimed at technological innovation and entrepreneurship (ETZKOWITZ; ZHOU, 2017; ANDRADE *et al.*, 2023).

According to Dudin *et al.* (2020), in developed countries, such as the United States, Japan, Canada, some European countries, such as the Netherlands and even Belarus, there is an established tradition of interaction between universities and other research institutes, industry and government. In the comparative analysis of European countries in technological innovation, Mejlgaard *et al.* (2019) found that universities stand out with their essential contributions to the general conditions of technological innovation, in the framework of their links with the industry, together with the role of the government as a provider of incentives for innovation, mainly through funding and public policies.

A successful case of this dynamic, in emerging economies is the Taiwanese chip industry, where universities acted as strategic licensing and patent agents (LEE; YOON, 2010). Another example is China, where increased collaboration between universities, industry, and government has been identified as a mechanism to increase the productivity of the Chinese innovation system and help it to develop the necessary capabilities (ZHAO *et al.*; 2015).

TRIPLE HELIX IN BRAZIL

There is a differentiation of the Brazilian actions to technological innovation when compared to the countries of the Organization for Economic Cooperation and Development (OECD). It is worth remembering that, in Brazil, the leading role in the activities of developing new technologies, especially in areas recognized as high technology, belongs to the university, more than to the industry. In this context, when the number of companies that develop activities focused on technological innovation is still small, universities assume an important strategic role in terms of scientific and technological production (DALMARCO, *et al.*, 2018; DALMARCO, *et al.*, 2019; FISCHER *et al.*, 2019; DUDIN *et al.*, 2020; BASSO *et al.*, 2021; ANDRADE et al, 2022; ATHAYDE *et al.*, 2022; NASCIMENTO *et al.*, 2022; RIBEIRO; NAGANO, 2023).

In this context, public universities have become responsible for Brazil's scientific and technological production. A report prepared by Clarivate Analytics in 2017, and published by CAPES, shows the predominance of research in public universities. Among the 20 most productive institutions (in terms of publication of articles), and therefore those with the greatest impact, are 15 federal universities and five (5) state universities (CROSS *et al.*, 2017). They are also the most responsible for patent applications, considering only Brazilian institutions (CROSS *et al.*, 2017; INPI, 2018; BASSO *et al.*, 2021).

Nevertheless, Andrade *et al.* (2022) observed that in Brazil, interactions between universities and industry have been sporadic and limited, with the government acting as an intermediary between these two actors, mainly in the elaboration of legislation (BRAZIL, 2004; 2016; 2018) and public policies to promote innovation, as well as in the financing of technological innovation. As a result, the flows of knowledge and technology have not been sufficient for the country to reach TH maturity. Thus, the contributions of universities to technological innovation are still below the possibilities promoted by the TH model.

In line with Graef *et al.* (2022), Basso *et al.* (2021) and Dalmarco *et al.* (2019), in Brazil, relationships within the TH are a limited and sporadic due to the low adherence of industry to collaborative technology development, characterized by a low number of collaborative innovation projects and a low number of technology transfer agreements. As a result, Brazilian universities have been active in research development, but still have difficulties in transferring knowledge and technology to productive sectors.

According to De Oliveira *et al.* (2022), there are cultural barriers, institutional barriers, structural barriers and relational barriers that make it difficult to transfer technologies from universities to society. A complicating aspect, according to Nascimento *et al.* (2022) relates to ideological issues regarding the role of the public university in Brazil. This is equivalent to stating that, when assuming responsibilities arising from activities involving teaching, research and extension, the university must collaborate to promote economic and social development through the transfer of knowledge, a characteristic that is in line with North American university tradition, for example, but it conflicts with the values that support public universities in Brazil.

Ribeiro and Nagano (2023) studied how the Triple Helix influences the performance of Brazilian organizations in university-industry-government collaborations. The authors' findings show that the organizational structure affects not only the relationship among members, but also the flow of knowledge and how relational elements (collaborative culture, trust and leadership) facilitate knowledge sharing. In addition, the context influences these three other dimensions. The main obstacles identified were cultural differences, bureaucracy, and the socio-economic realities, while the facilitators were the existence of technology parks and incubators, government incentives and geographic proximity between universities and industry.

In addition, Athayde *et al.* (2022), realized from an interview with professors about the possibilities and difficulties of integration in the Triple Helix. Four practical issues emerged as important dimensions that influence the capacity for integration between actors: fragility and lack of institutional support to guarantee legal stability; professors' motivations; the need for external agents to be interested in the activities carried out at the university and, finally, the importance of an administrative technological structure capable of providing support.

Another peculiarity is that in Brazil, funding for Science, Technology and Innovation (ST&I) comes mostly from the public budget. National agencies such as the Coordination for the Improvement of Higher Education Personnel (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES*), the National Council for Scientific and Technological Development (*Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq*), and the Studies and Projects Funding (*Financiadora de Estudos e Projetos – FINEP*) are responsible for distributing most of the federal funds (CROSS *et al.*, 2017; DALMARCO, *et al.*, 2018; DALMARCO, *et al.*, 2019; BASSO *et al.*, 2021; ANDRADE et al, 2022). Government (state) funding is provided primarily through state foundations, as described below.

Fischer *et al.* (2019) argued that in emerging economies, such as the Brazilian case, these partnerships are, with some exceptions, at an early stage, and studies with conceptual TH basis are still scarce, especially for national contexts. Given the nature of innovation systems, universities play a central role. This is very relevant for Brazil. Despite the cited works, there is not enough knowledge about how universities are related to innovation systems in Brazil. This is another motivation for the present work, based on the Brazilian context.

FACTOR ANALYSIS CONTRIBUTIONS TO THE TRIPLE HELIX THEORY

In Poland, Bieliński and Tomczyńska (2019) noticed an interesting case for empirical study of the scientific ethos, mainly because in a relatively short period of time the country experienced a significant reform of the scientific system, especially in terms of evaluation and financing of scientific work. Therefore, they conducted a survey questionnaire among 801 researchers, who were given ten (10) statements (constructs) for evaluation on an 11-point numerical scale, which were studied using CFA and fuzzy clustering.

Bieliński and Tomczyńska (2019) argued that the TH policy, aimed at strengthening the links between science and business, further strengthened the need for the expert science and, at least to some extent, initiated a fusion of the norms of academic and the industrial science. They identified three (3) distinct groups of researchers guided by different sets of values and norms in their professional conduct (academic science, post-academic science, and the industrial science) and a cluster of researchers with an unidentified system of principles. The results of the study indicate that many scientists were willing to collaborate with business, given the relatively recent development of policies to strengthen links between universities and industry.

According to Fitriani *et al.* (2019), the TH model can help small and medium enterprises (SMEs) to improve their business. They cited that the topic and the three (3) actors have not been optimally synergized in the development of SMEs. Therefore, the purpose of their study was to identify the critical success factors of the TH model for SMEs. The questionnaire-based survey using Likert scale was conducted on thirty SMEs in Banten and Bandung in Indonesia to validate a list of 37 success factors (constructs).

The findings of Fitriani *et al.* (2019) were analyzed using a CFA approach to illustrate the success of the TH model. They found that the 37 items of critical success factors had good content validity and correct internal consistency, or excellent homogeneity reliability. Based on these success factors, a six (6) stage TH model was developed. They found that the university, as a knowledge transfer and research leader for the community, plays a significant role in the development of either the local or national economy.

By studying Thai SMEs in food manufacturing, Ueasangkomsate and Jangkot (2019) provided insights into TH collaboration in product and process innovation. They conducted a questionnaire-based survey with a seven-point Likert scale to test five (5) constructs. The results showed that the collaboration of SMEs in TH was not so high, especially with regard to the government. SMEs collaborating with universities played an important role in transferring research knowledge as well as supporting human development for the food industry. However, this research did not find a significant relationship between SMEs collaborating with universities and innovation performance, for reasons related to the different research focus of these two (2) sectors.

In the United States, Mendoza *et al.* (2020) examined academic norms related to faculty engagement with industry at a public research-intensive university in the fields of Science, Technology, Engineering, Mathematics, and Medicine (STEMM). Methods included EFA and CFA, logistic regression, and ANOVA applied to responses to a 4-point Likert scale survey instrument. Constructs were implemented based on current literature on university-industry linkages.

The study by Mendoza *et al.* (2020) supports the role of faculty as TH actors that link the public and private spheres. Their results show how faculty accepted the coexistence of different logics in their norms, which differ by category, type of involvement with the industry, previous work experience in the industry, and field. In general, the professors in this study have values traditionally associated with the academic profession, except when there were opportunities for market participation and the pursuit of commercial benefits from research.

In Germany, Lerman *et al.* (2021) argued that TH can play an important role in supporting and establishing local policies for renewable energy systems (RES). They analyzed the contribution of the TH actors to the development of three (3) innovation policy criteria (constructs) for RES development: creation of cooperative systems, generation and transfer of knowledge, and development of municipal locational factors. The data they analyzed were collected through an online survey, coupled with telephone interviews, measured using a 7-point Likert scale or a double-item scale. The CFA was performed in Stata 13.0™.

Lerman *et al.* (2021) found that government and industry play an important role in all three (3) policy criteria. At the same time, they found only a contribution of universities to knowledge generation and transfer, but not to the other two criteria. Thus, in the context studied by them, the integration of government and industry is being a driving factor to create innovative conditions for the development of RES, while universities focus on the creation of structural knowledge for innovation.

Muhamad *et al.* (2021) conducted a 5-point Likert scale questionnaire-based survey among 540 university stakeholders representing alumni, community and industry from the southern, northern and eastern regions of Malaysia. The data were subjected to CFA using structural equation modeling (SEM). Muhamad *et al.* (2021) addressed the role of universities in the economic growth and social development of communities and showed that universities influence the economic development and well-being of communities, thereby fulfilling their community-related roles.

The present approach differs from previous work. Note that unlike others, we used EFA to study the interactions between universities, industry and government in the light of TH theory. We did not rely on previously established constructs, and the use of EFA would provide information about the number of latent factors needed to represent data from a database collected from eight (8) Brazilian public universities. Another difference is the use of only quantitative observable variables, avoiding the use of Likert scales, as recommended by Fávero and Belfiore (2019).

It is also important to note that in all the papers cited in this section, the present authors emphasized the importance of universities for technological innovation according to the TH theory. In each country or context, differences in the action or interaction conditions for universities as well as industry and government could be verified. This is another motivation for this work in order to contribute to the TH literature by offering an analysis in the Brazilian context. At the same time, it focuses on the contributions of Brazilian public universities to technological innovation.

METHODOLOGY

This research work was conducted in the form of an applied investigation. The approach was mainly quantitative, using mathematical and statistical tools. In order to study the relationship between variables, a multivariate EFA technique was used to develop a diagnosis of the data behavior under analysis and to obtain information about the phenomenon under observation. The more variables are used in a survey, the more they tend to correlate with each other. In these cases, a researcher must look for ways to manage them by grouping them and creating latent factors that can represent a set of the observable variables. The factors aim to summarize the variance into a smaller set, with a minimum loss of variance information (FÁVERO; BELFIORE, 2019).

In order to start the data collection and processing, it was necessary to select the objects of study. The criterion used was the number of patents filed by the National Institute of Industrial Property (*Instituto Nacional de Propriedade Industrial, INPI*) (INPI, 2018). Initially, 16 public universities were selected from among those with the highest scores in the year 2017 according to the INPI (2018). However, some universities did not publish all of their data, therefore, so the data of eight institutions in the initial sample were analyzed in this work: Unesp; UFPR; UFRGS; UFSCar; Unicamp; UFBA; UFV and UFPE, located in three different Brazilian regions (Southeast, South and Northeast).

The choice of observable variables was inspired by Zhao *et al.* (2015), Cross *et al.* (2017) and Andrade *et al.* (2022), considering the specificities of Brazilian public universities, quantitative aspects of the internal environment of the institution, such as their faculty and students, their involvement in research groups, the production of papers and patents and interactions with other actors through public funding, project innovation in collaboration with third parties, technology transfer agreements and the value obtained from technology. Thus, as shown in Supplementary Table S1, the observable variables describe: faculty; students; research environment; publication of papers; patents filed and granted; interactions between universities and government; and interactions between universities and industry.

The observable variables of faculty, students, research environment, publication of articles and patents filed and granted, presented in Table 1, address endogenous issues of eight (8) Brazilian public universities included in this study. These data are mainly individual characteristics of the universities. However, in order to understand how these endogenous issues affect the contributions of Brazilian public universities to technological innovation, according to the TH theory, parameters capable of quantifying the interactions of these universities with government and industry were included.

Data were extracted from the reports listed in the references: UFBA (2019); UFPE (2019); UFSCar (2019); UFV (2019); UFPR (2019); UFRGS (2019). When data were not available from these sources, a new search was conducted considering other publication sources, such as statistical yearbooks: Unesp (2019) and Unicamp (2018); or sectoral management reports: CNPq (2019) and CAPES (2019).

Table 1 – Observable variables related to quantitative aspects of the Brazilian public universities and the corresponding axes of the TH.

Quantitative aspects of Brazilian public universities	Observable variables	Triple Helix Axis*
Faculty	Number of professors	A
	Number of PhD professors	A

Students	Number of students Number of undergraduate students Number of graduate students Number of master's students Number of PhD students Student to professor ratio Student to PhD professor ratio	A A A A A A A
Research environment	Number of research groups on the CNPq Lattes Platform Number of researchers Number of PhDs involved in research groups Number of research groups per professor Number of research groups per PhD professor Number of research groups per student Percentage of PhDs involved in research groups Researchers per number of research groups PhDs involved in research groups per research group	A A A A A A A A A
Publication of papers	Number of papers published Number of papers published per professor Number of papers published per PhD professor Number of papers published per student Number of papers published per research group Number of papers published per researcher	A A A A A A
Patents filed and granted	Number of patents filed Number of patents filed in Brazil Number of patents filed in other countries Number of patents granted Number of patents granted in Brazil Number of patents granted in other countries Number of patents filed per professor Number of patents filed per PhD professor Number of patents filed per student Number of patents filed per research group Number of patents filed per researchers Percentage of patents filed in Brazil per number of patents filed Percentage of patents filed in other countries per number of patents filed Number of patents granted per number of patents filed Number of patents granted in Brazil per number of patents filed in Brazil Number of patents granted in other countries per number of patents filed in other countries Percentage of patents granted in Brazil per number of patents granted Percentage of patents granted in other countries per number of patents granted	A A A A A A A A A A A A A A A A A A
Interactions between universities and government	Public funding Public funding received through CNPq Public funding received through CAPES Public funding received through FINEP Public funding received through the state foundations Public funding per professor Public funding per PhD professor	G G G G G G G

	Public funding per student	G
	Public funding per research groups	G
	Public funding per researcher	G
	Public funding per paper published	G
	Public funding per patents filed	G
	Public funding per number of technology transfer agreement	G
	Public funding per money generated from technology transfer	G
Interactions between universities and industry	Number of innovation projects in cooperation with third parties	I
	Number of technology transfer agreement	I
	Money generated from technology transfer	I
	Number of innovation projects in cooperation per professor	I
	Number of innovation projects in cooperation per PhD professor	I
	Number of innovation projects in cooperation per student	I
	Number of innovation projects in cooperation per research group	I
	Number of innovation projects in cooperation per researcher	I
	Number of technology transfer agreement per patents filed	I
	Number of technology transfer agreement per professor	I
	Number of technology transfer agreement per PhD professor	I
	Number of technology transfer agreement per student	I
	Number of technology transfer agreement per number of research groups	I
	Number of technology transfer agreement per researchers	I
	Money generated from technology transfer per professor	I
	Money generated from technology transfer per PhD professor	I
	Money generated from technology transfer per student	I
	Money generated from technology transfer per number of research groups	I
	Money generated from technology transfer per researchers	I
	Money generated from technology transfer per number of technology transfer agreement	I

Source: Prepared by the authors.

*Note: According to TH theory, A describes the endogenous issues of academia; I shows the interaction between academia and industry; and G shows the interaction between academia and government.

The EFA analyses of this work were performed using the IBM™ SPSS™ software, base 2020 (20.0), applied to the medians of 76 observable variables (Table 1), in the observations of the eight Brazilian public universities in the period from 2008 to 2015. EFA is particularly useful when the intention is to work with variables that have high correlation coefficients, allowing the identification of latent factors that capture most of the variance in the observable variables. EFA is intended to represent a multivariate random process by creating latent factors, derived from the observable variables and, generally, in smaller numbers, it represents the commonalities of the process. Among the main methods for determining latent factors, the one known as Principal Components (PC) is the most widely used (FÁVERO; BELFIORE, 2019).

Given *t* observations on *n* variables, EFA reduces the dimensionality of a data matrix by finding p latent factors with $p \leq n$ (F_1, F_2, ... F_p). Thus, the first factor is the direction through the data that explains the most variance. The second and subsequent factors must be orthogonal to the previous factor and describe the maximum amount of remaining variance (HAIR *et al.*, 2019).

Thus, for *n* variables we have (FÁVERO; BELFIORE, 2019):

$$\begin{aligned} F_1 &= s_{11}.\ X_{1i} + s_{21}.\ X_{2i} + \cdots s_{n1}.\ X_{ni} \\ F_2 &= s_{12}.\ X_{1i} + s_{22}.\ X_{2i} + \cdots s_{n2}.\ X_{ni} \\ &\vdots \\ F_p &= s_{1p}.\ X_{1i} + s_{2p}.\ X_{2i} + \cdots s_{np}.\ X_{ni} \end{aligned} \tag{1}$$

where the *s* terms are known as factor scores and relate a given factor to the observable variables. Factor scores can be calculated by determining the eigenvalues (λ) and eigenvectors (*v*) of Pearson's correlation matrix (PEARSON, 1901). Since a factor represents a grouping of observable variables, only factors extracted from eigenvalues greater than one (1) are considered; this criterion is commonly used and is known as the Latent Root criterion or Kaiser criterion (KAISER, 1960). Factors extracted from eigenvalues less than one (1) usually do not even represent the behavior of an observable variable (FÁVERO; BELFIORE, 2019).

The vectors of the factor scores can be defined as follows (FÁVERO; BELFIORE, 2019):

$$S_n = \begin{pmatrix} s_{1n} \\ \vdots \\ s_{nn} \end{pmatrix} = \begin{pmatrix} \dfrac{v_{1n}}{\sqrt{\lambda_n^2}} \\ \vdots \\ \dfrac{v_{nn}}{\sqrt{\lambda_n^2}} \end{pmatrix} \tag{2}$$

Once the factors are determined, the factor loadings (*c*) are defined, which are Pearson's correlation coefficients (PEARSON, 1901) between the observable variables and each of the factors. In cases where $p = n$, the sum of the squares of these charges is always equal to 1. In cases where $p < n$ this sum will not equal 1. This sum (Equation (3)) is called the commonality:

$$\begin{aligned} c_{11}^2 + c_{12}^2 + \cdots &= commonality\ X_1 \\ c_{21}^2 + c_{22}^2 + \cdots &= commonality\ X_2 \\ &\vdots \\ c_{n1}^2 + c_{n2}^2 + \cdots &= commonality\ X_n \end{aligned} \tag{3}$$

The analysis of commonalities verifies whether the observable variables under study share a significant percentage of variance with the extracted factors, and thus it is possible to define which observable variables will constitute the EFA.

Although there is no theoretical cut-off point from which a given commonality can be considered high or low, but the presence of low commonalities in relation to the others may suggest that the observable variable should not be included in the EFA analysis (FÁVERO; BELFIORE, 2019).

Finally, to better visualize the observable variables most represented by a given factor, one could think of rotating the extracted factors around the origin, the new factors are called rotated factors. The Varimax Orthogonal Rotation was used, whose objective is to minimize the number of variables with high loads in each factor by redistributing the factor loads and maximizing the shared variance in the factors corresponding to lower eigenvalues (FÁVERO; BELFIORE, 2019; KAISER, 1958). In rotation, for each observable variable under analysis, the factor loadings are increased for one factor and decreased for the other. This increased the quality of the EFA, without changing the analysis of commonalities.

RESULTS

Thus, following the methodology described in the previous section, using the median of 76 observable variables, it was thus possible to perform an EFA analysis considering the PC method. Table 1 presents seven (7) quantitative aspects of Brazilian public universities covering 71.4% of the TH academy axis and 14.3% of both the TH government and innovation axes. Counting only the observable variables, from Table 1 the TH axes were divided into 55.3% for academy, 26.3% for industry and 18.4% for government, showing that there are more academy issues when considering the TH model in these eight (8) Brazilian universities.

Considering the results of EFA from SPSS™ software, Table 2 shows the eigenvalues (Eigenvalue column) for the total variance (Total Percentage column) and the accumulated total variance (Cumulative Percentage column). The six (6) factors with eigenvalues are greater than one (1) according to the Kaiser criterion (KAISER, 1960) are shown.

Table 2 – Eigenvalues, shared variance and cumulative shared variance for each of the rotated factors considered.

Total Variance Explained			
PC axis (n)	Initial Eigenvalues		
	Eigenvalue	Total Percentage (%)	Cumulative Percentage (%)
Factor 1	27.614	36.334	36.334
Factor 2	17.266	22.719	59.053
Factor 3	13.910	18.303	77.356
Factor 4	10.854	14.281	91.637
Factor 5	4.006	5.272	96.909
Factor 6	1.576	2.074	98.982

Source: Prepared by the authors in SPSS™.

From the Total Percentage column of Table 2, it is possible to state that 36.334% of the total variance is shared for the formation of the Factor 1, 22.719% are shared for the formation of the Factor 2, 18.303% for the formation of the Factor 3, 14.281% for the Factor 4, 5.272% for the Factor 5, and 2.074 for the Factor 6. From this observation, it can be seen that the six (6) factors share a in total of 98.982% of the variance of the observable variables. Therefore, for the formation of these factors, the loss of variance was only 1.018%, so the use of observable variables for EFA is high and, therefore, the result of this exploratory analysis describes the behavior of the observable variables.

The dimensional reduction is therefore remarkable, going from 76 observable variables to only six (6) factors with an enormous representation (of almost 99%). It is also noteworthy that only the first two (2) factors cover 59.053% of the data, which is surprising. And the first four (4) factors cover 91.637% of the data, as shown in the Cumulative Percentage column of Table 2.

The commonalities are presented in Table 3. The goal of this analysis was to determine if any of the observable variables did not share a significant percentage of variance with the latent factors presented in Table 2. The results of the commonalities presented in Table 3 show that almost all of the observable variables had a commonality greater than 0.9. Only one observable variable (Public funding per number of technology transfer agreements) had a commonality of 0.815, but this value was not considered low. Thus, all 76 observable variables could be included in the EFA with the assurance that a lower percentage of the total shared variance is lost in the formation of factors.

Table 3 – Commonality of each of the observable variables, according to Equation (3), which represents the total variance shared by each of the observable variables across all factors.

Observable Variables	Extraction
Number of research groups on the CNPq Lattes Platform	.999
Number of researchers	.995
Number of PhDs involved in research groups	.996
Number of professors	1.000
Number of PhD professors	1.000
Number of students	1.000
Number of undergraduate students	.999
Number of graduate students	.995
Number of master's students	.993
Number of PhD students	.999
Number of innovation projects in cooperation with third parties	1.000
Number of papers published	.999
Number of patents filed	.967
Number of patents filed in Brazil	.985
Number of patents filed in other countries	.993
Number of patents granted	.997
Number of patents granted in Brazil	.999
Number of patents granted in other countries	.985
Number of technology transfer agreement	.986
Money generated from technology transfer	.998
Public funding	.996
Public funding received through CNPq	.992
Public funding received through CAPES	.997
Public funding received through FINEP	1.000
Public funding received through the state foundations	.972
Student to professor ratio	.997
Student to PhD professor ratio	.958
Number of research groups per professor	.999
Number of research groups per PhD professor	.976
Number of research groups per student	.996
Percentage of PhDs involved in research groups	.997

Researchers per number of research groups	.959
PhDs involved in research groups per research group	.980
Number of innovation projects in cooperation per professor	1.000
Number of innovation projects in cooperation per PhD professor	1.000
Number of innovation projects in cooperation per student	1.000
Number of innovation projects in cooperation per research group	1.000
Number of innovation projects in cooperation per researcher	1.000
Public funding per professor	.999
Public funding per PhD professor	.996
Public funding per student	1.000
Public funding per research groups	.988
Public funding per researcher	1.000
Number of papers published per professor	.991
Number of papers published per PhD professor	.995
Number of papers published per student	.995
Number of papers published per research group	.990
Number of papers published per researcher	.994
Public funding per paper published	.998
Number of patents filed per professor	1.000
Number of patents filed per PhD professor	.992
Number of patents filed per student	1.000
Number of patents filed per research group	1.000
Number of patents filed per researchers	.996
Public funding per patents filed	.980
Percentage of patents filed in Brazil per number of patents filed	.973
Percentage of patents filed in other countries per number of patents filed	.973
Number of patents granted per number of patents filed	.997
Number of patents granted in Brazil per number of patents filed in Brazil	1.000
Number of patents granted in other countries per number of patents filed in other countries	.994
Percentage of patents granted in Brazil per number of patents granted	1.000
Percentage of patents granted in other countries per number of patents granted	1.000
Number of technology transfer agreement per patents filed	.930
Number of technology transfer agreement per professor	.997
Number of technology transfer agreement per PhD professor	.999
Number of technology transfer agreement per student	1.000
Number of technology transfer agreement per number of research groups	.998
Number of technology transfer agreement per researchers	.997
Public funding per number of technology transfer agreement	.815
Money generated from technology transfer per professor	.999
Money generated from technology transfer per PhD professor	.999
Money generated from technology transfer per student	.999
Money generated from technology transfer per number of research groups	.999
Money generated from technology transfer per researchers	.999
Public funding per money generated from technology transfer	.944
Money generated from technology transfer per number of technology transfer agreement	.996

Source: Prepared by the authors in SPSS™.

Table 4 presents the factor scores rotated by the Varimax method, from which the expressions of the new factors can be obtained. The factor scores corresponding to each factor, i.e., each column of Table 4, are the estimated parameters of a multiple linear regression model representing the factor itself according to Equation (1).

Table 4 – Rotated factor scores corresponding to each of the observable variables standardized by the corresponding eigenvalues (Equation (2)) for each of the factors.

Observable variables	Factor					
	1	2	3	4	5	6
Number of research groups on the CNPq Lattes Platform	-.006	.054	.005	-.004	.005	.010
Number of researchers	-.012	.055	.005	.004	.014	-.013
Number of PhDs involved in research groups	-.008	.052	.003	.008	-.001	.008
Number of professors	-.035	.058	-.007	-.002	-.009	-.001
Number of PhD professors	-.026	.059	-.008	-.002	-.019	.040
Number of students	-.031	.062	-.011	-.009	.048	-.018
Number of undergraduate students	-.033	.055	-.014	-.013	.036	-.062
Number of graduate students	-.013	.053	.007	.006	.048	.094
Number of master’s students	-.019	.056	.007	.002	.024	.103
Number of PhD students	-.007	.048	.005	.010	.065	.079
Number of innovation projects in cooperation with third parties	.002	.001	.063	-.005	.015	-.026
Number of papers published	-.009	.031	.000	.046	-.046	-.058
Number of patents filed	-.006	.004	.009	.059	.062	-.010
Number of patents filed in Brazil	-.004	-.006	.016	.065	.034	-.055
Number of patents filed in other countries	.012	.041	-.006	.000	.101	.038
Number of patents granted	.031	.002	-.016	.008	.057	.080
Number of patents granted in Brazil	.038	-.001	-.017	.001	.044	.058
Number of patents granted in other countries	.070	-.008	.016	-.020	-.005	-.144
Number of technology transfer agreement	.015	.033	-.015	.016	-.007	-.045
Money generated from technology transfer	.003	-.008	.073	.006	-.051	-.013
Public funding	.006	.048	-.008	.001	.039	.032
Public funding received through CNPq	-.024	.036	.025	.016	.049	.185
Public funding received through CAPES	-.003	.049	.010	.005	.012	.011
Public funding received through FINEP	.000	.053	.002	.000	.045	-.072
Public funding received through the state foundations	.021	.038	-.026	-.008	.036	-.010
Student to professor ratio	.027	.007	-.007	-.028	.215	-.053
Student to PhD professor ratio	-.013	-.006	-.011	-.008	.130	-.137
Number of research groups per professor	.062	-.020	.022	-.013	.021	-.041
Number of research groups per PhD professor	.069	-.041	.032	-.012	.025	-.109
Number of research groups per student	.062	-.024	.028	-.012	-.057	-.038
Percentage of PhDs involved in research groups	.023	-.007	.002	.022	-.091	.104
Researchers per number of research groups	-.045	.025	-.005	.048	.053	-.094
PhDs involved in research groups per research group	-.026	.020	-.004	.070	-.032	.021
Number of innovation projects in cooperation per professor	.007	-.002	.065	-.005	.015	-.041
Number of innovation projects in cooperation per PhD professor	.007	-.001	.064	-.008	.021	-.055
Number of innovation projects in cooperation per student	.006	-.002	.065	-.004	.013	-.039

Number of innovation projects in cooperation per research group	.004	.001	.061	-.011	.028	-.050
Number of innovation projects in cooperation per researcher	.005	.000	.062	-.011	.025	-.045
Public funding per professor	.047	.001	-.003	-.004	.069	-.010
Public funding per PhD professor	.047	-.003	-.003	-.005	.082	-.010
Public funding per student	.048	.001	-.001	-.005	.033	-.003
Public funding per research groups	.029	.020	-.020	-.003	.086	.053
Public funding per researcher	.044	.007	-.012	-.019	.058	.051
Number of papers published per professor	.004	.003	.001	.061	-.017	-.040
Number of papers published per PhD professor	-.004	-.004	.004	.071	-.044	-.059
Number of papers published per student	.001	.003	.003	.063	-.048	-.046
Number of papers published per research group	-.015	.003	.000	.071	-.079	-.077
Number of papers published per researcher	-.011	.004	.000	.069	-.077	-.052
Public funding per paper published	.039	-.007	-.007	-.076	.115	-.116
Number of patents filed per professor	.002	-.014	-.005	.051	.065	.082
Number of patents filed per PhD professor	-.008	-.020	-.006	.059	.045	.095
Number of patents filed per student	-.001	-.020	-.001	.057	.034	.086
Number of patents filed per research group	-.018	-.021	-.003	.071	.016	.057
Number of patents filed per researchers	-.016	-.027	-.005	.066	.008	.101
Public funding per patents filed	.001	.045	-.018	-.039	-.038	.042
Percentage of patents filed in Brazil per number of patents filed	-.009	-.040	.000	.039	.031	-.100
Percentage of patents filed in other countries per number of patents filed	.009	.040	.000	-.039	-.031	.100
Number of patents granted per number of patents filed	.062	-.025	.006	-.035	-.090	-.048
Number of patents granted in Brazil per number of patents filed in Brazil	.057	-.027	.001	-.033	-.075	.002
Number of patents granted in other countries per number of patents filed in other countries	.075	-.015	.015	-.034	-.061	-.173
Percentage of patents granted in Brazil per number of patents granted	-.025	.018	-.021	-.009	-.018	.466
Percentage of patents granted in other countries per number of patents granted	.056	.002	.039	-.013	-.031	-.112
Number of technology transfer agreement per patents filed	.015	.029	-.007	-.011	-.085	-.044
Number of technology transfer agreement per professor	.045	.003	-.008	.012	.020	-.099
Number of technology transfer agreement per PhD professor	.044	.000	-.007	.016	.002	-.102
Number of technology transfer agreement per student	.042	-.003	-.016	.014	-.004	-.068
Number of technology transfer agreement per number of research groups	.035	.010	-.008	.020	-.030	-.110
Number of technology transfer agreement per researchers	.042	.005	-.007	.010	-.043	-.112
Public funding per number of technology transfer agreement	.003	-.029	.041	.031	-.070	.152
Money generated from technology transfer per professor	.006	-.010	.074	.005	-.052	-.020

Money generated from technology transfer per PhD professor	.006	-.010	.074	.005	-.053	-.019
Money generated from technology transfer per student	.006	-.010	.074	.005	-.053	-.020
Money generated from technology transfer per number of research groups	.005	-.009	.073	.005	-.052	-.017
Money generated from technology transfer per researchers	.006	-.010	.074	.005	-.053	-.020
Public funding per money generated from technology transfer	.011	.040	-.009	-.005	-.035	-.001
Money generated from technology transfer per number of technology transfer agreement	.030	-.015	.073	.001	-.030	-.068

Source: Prepared by the authors in SPSS™.

Table 5 shows the rotated factor loadings, which correspond to Pearson's correlation coefficients (PEARSON, 1901) between the observable variables and each factor. The highest factor loading for each observable variables is highlighted, indicating a higher correlation of the observable with that factor. From the Varimax rotation, it was noticed that as the factor loading increased, other factors decreased. Thus, there was a greater correlation of the observable variables with the factor for which the load increased.

Considering the factor loadings, when analyzing each column of Table 5, to identify the highest correlations, it was possible to notice that: Factor 1 has a higher correlation with the number of research groups per student, including 13 A, 5 G and 5 I TH axes; Factor 2 is mainly correlated with the number of Ph.D. professors, including 14 A, 6 G and 2 I TH axes; in particular, four (4) observable variables tied for the highest correlation with Factor 3, namely: money generated from technology transfer per professor, money generated from technology transfer per Ph.D. student, money generated from technology transfer per researcher and money generated from technology transfer per Ph.D. professor. This factor also includes 2 G and 13 I TH axes; Factor 4 has a higher correlation with the number of papers published per Ph.D. professor, including 13 A and 1 G TH axes; Factor 5 is mainly correlated with the observable variable student to professor ratio (A TH axis); and Factor 6 has a higher correlation with the percentage of patents granted in Brazil per number of patents granted (also an A TH axis).

Table 5 – Rotated factor loadings corresponding to Pearson's correlation coefficients (PEARSON, 1901) between the observable variables and each of the factors.

Observable variables	**Triple Helix Axis***	**Factor**					
		1	**2**	**3**	**4**	**5**	**6**
Number of research groups on the CNPq Lattes Platform	A	.161	.965	.199	.031	-.044	.001
Number of researchers	A	.048	.967	.202	.123	.000	-.053
Number of PhDs involved in research groups	A	.183	.948	.150	.192	-.061	-.006
Number of professors	A	-.385	.905	.022	-.095	-.127	-.090
Number of PhD professors	A	-.120	. 976	.018	-.044	-.176	.005
Number of students	A	-.382	.899	.055	-.132	.111	-.117
Number of undergraduate students	A	-.560	.761	-.046	-.242	.057	-.207
Number of graduate students	A	.222	.855	.357	.187	.170	.154

Number of master's students	A	.119	.911	.341	.078	.055	.156
Number of PhD students	A	.320	.793	.328	.279	.251	.140
Number of innovation projects in cooperation with third parties	I	-.131	.108	.968	-.073	.169	-.002
Number of papers published	A	.137	.704	-.064	.644	-.222	-.130
Number of patents filed	A	.184	.097	.233	.870	.335	-.008
Number of patents filed in Brazil	A	.117	-.001	.241	.922	.235	-.084
Number of patents filed in other countries	A	.528	. 683	.161	.246	.392	.093
Number of patents granted	A	.861	.105	-.125	.357	.238	.213
Number of patents granted in Brazil	A	.904	.082	-.200	.270	.171	.181
Number of patents granted in other countries	A	.950	.248	.031	.054	-.025	-.126
Number of technology transfer agreement	I	.499	.724	-.235	.379	-.098	-.071
Money generated from technology transfer	I	-.063	.074	.989	.027	-.093	.032
Public funding	G	.456	.859	.037	.190	.097	.063
Public funding received through CNPq	G	.141	.525	.682	.252	.248	.326
Public funding received through CAPES	G	.250	.914	.260	.178	.007	.016
Public funding received through FINEP	G	.122	.952	.152	.134	.128	-.144
Public funding received through the state foundations	G	.599	.708	-.307	.119	.057	.000
Student to professor ratio	A	.277	-.091	.200	-.094	.928	-.042
Student to PhD professor ratio	A	-.627	-.379	-.039	-.131	.566	-.288
Number of research groups per professor	A	.953	-.047	.230	.118	.135	.067
Number of research groups per PhD professor	A	.830	-.390	.290	.109	.194	-.038
Number of research groups per student	A	.956	-.009	.179	.058	-.202	.073
Percentage of PhDs involved in research groups	A	.779	.158	-.105	.381	-.384	.247
Researchers per number of research groups	A	-.694	.269	.036	.527	.234	-.267
PhDs involved in research groups per research group	A	.020	.412	-.051	.890	-.121	-.009
Number of innovation projects in cooperation per professor	I	-.076	.096	.976	-.046	.173	-.019
Number of innovation projects in cooperation per PhD professor	I	-.120	.088	.963	-.094	.197	-.045
Number of innovation projects in cooperation per student	I	-.086	.091	.977	-.042	.168	-.015
Number of innovation projects in cooperation per research group	I	-.166	.090	.946	-.138	.220	-.044
Number of innovation projects in cooperation per researcher	I	-.152	.084	.953	-.136	.207	-.034
Public funding per professor	G	.902	.159	.003	.261	.294	.079
Public funding per PhD professor	G	.887	.081	.020	.255	.360	.082
Public funding per student	G	.935	.225	-.019	.219	.133	.093
Public funding per research groups	G	.805	.369	-.126	.244	.325	.150
Public funding per researcher	G	.930	.217	-.097	.039	.212	.178
Number of papers published per professor	A	.366	.238	-.066	.890	-.037	-.056
Number of papers published per PhD professor	A	.184	.135	-.074	.952	-.141	-.105
Number of papers published per student	A	.308	.278	-.091	.882	-.177	-.075
Number of papers published per research group	A	-.029	.255	-.177	.875	-.313	-.170
Number of papers published per researcher	A	.094	.275	-.173	.878	-.309	-.115
Public funding per paper published	G	.074	-.244	-.037	-.840	.450	-.153
Number of patents filed per professor	A	.410	-.248	.054	.782	.352	.177
Number of patents filed per PhD professor	A	.259	-.377	.024	.819	.279	.184

Number of patents filed per student	A	.362	-.316	.053	.825	.228	.181
Number of patents filed per research group	A	.031	-.381	-.007	.905	.160	.091
Number of patents filed per researchers	A	.122	-.478	-.033	.839	.123	.178
Public funding per patents filed	G	.158	.769	-.220	-.478	-.290	.049
Percentage of patents filed in Brazil per number of patents filed	A	-.390	-.740	-.090	.423	.220	-.192
Percentage of patents filed in other countries per number of patents filed	A	.390	.740	.090	-.423	-.220	.192
Number of patents granted per number of patents filed	A	.833	-.068	-.212	-.290	-.409	.029
Number of patents granted in Brazil per number of patents filed in Brazil	A	.851	-.165	-.225	-.265	-.337	.115
Number of patents granted in other countries per number of patents filed in other countries	A	.890	.190	-.121	-.193	-.286	-.178
Percentage of patents granted in Brazil per number of patents granted	A	.528	.087	.048	-.136	-.107	.825
Percentage of patents granted in other countries per number of patents granted	A	. 798	.435	.387	.077	-.106	-.078
Number of technology transfer agreement per patents filed	I	.348	.723	-.260	-.075	-.455	-.074
Number of technology transfer agreement per professor	I	.808	.299	-.227	.436	.064	-.099
Number of technology transfer agreement per PhD professor	I	.792	.286	-.248	.465	-.011	-.108
Number of technology transfer agreement per student	I	.800	.202	-.370	.421	-.047	-.053
Number of technology transfer agreement per number of research groups	I	.663	.461	-.296	.458	-.168	-.146
Number of technology transfer agreement per researchers	I	.735	.415	-.309	.347	-.224	-.136
Public funding per number of technology transfer agreement	G	.342	-.329	.553	.376	-.171	.335
Money generated from technology transfer per professor	I	-.039	.061	.991	.020	-.098	.025
Money generated from technology transfer per PhD professor	I	-.042	.062	.991	.019	-.098	.026
Money generated from technology transfer per student	I	-.041	.061	.991	.018	-.100	.025
Money generated from technology transfer per number of research groups	I	-.051	.066	.990	.022	-.097	.028
Money generated from technology transfer per researchers	I	-.042	.062	.991	.016	-.102	.025
Public funding per money generated from technology transfer	G	.425	.828	-.139	.053	-.237	.002
Money generated from technology transfer per number of technology transfer agreement	I	.303	.060	.944	.093	-.001	-.015

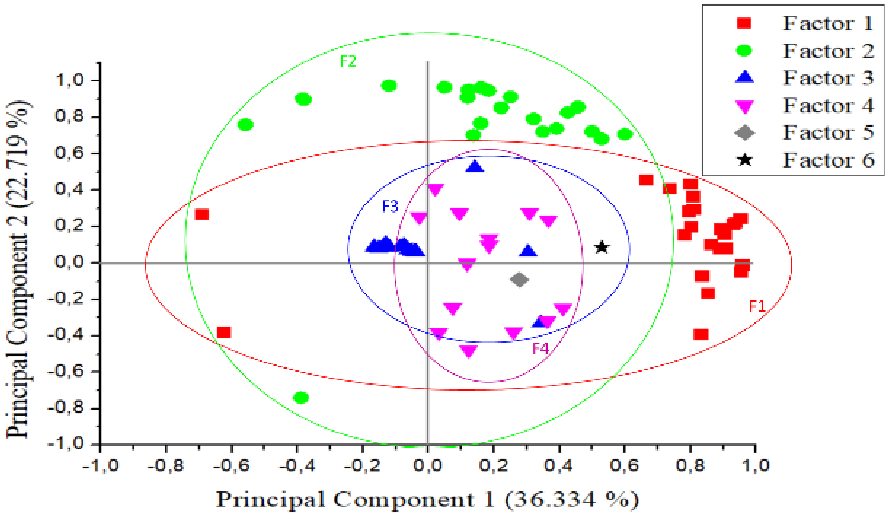
Source: Prepared by the authors in SPSS™.

*Note: According to the TH theory, A describes the endogenous issues of academia; I shows the interaction between academia and industry; and G shows the interaction between academia and the government. The highest factors in each row are highlighted in yellow. Highlighted in green are the twelve variables used by Andrade *et al.* (2022) for the same universities and time period analyzed. They used hierarchical and principal component analysis to classify these Brazilian universities.

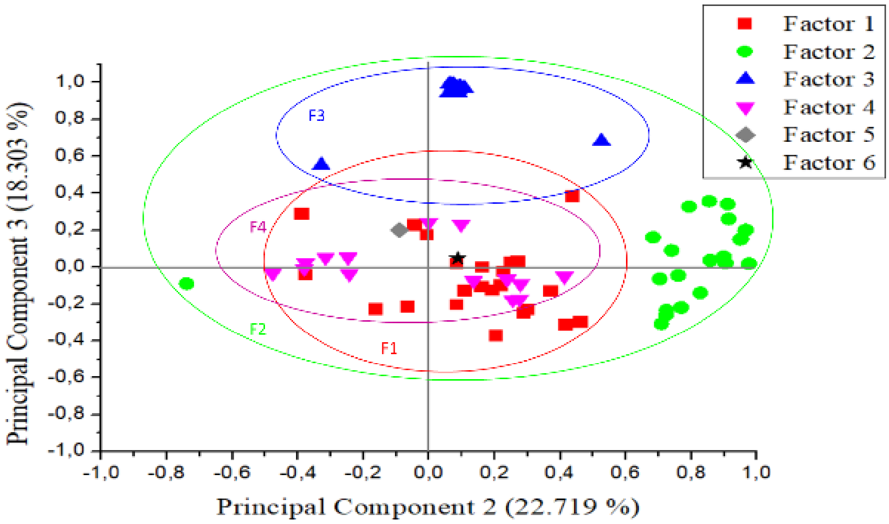
Table 5 shows that all of the observable variables were correlated with all of the factors; however, it is also clear that they always had one (1) higher correlation value with one (1) of the factors. The highest factor loading is highlighted in Table 5, indicating the highest correlation of the observable variables with that factor. Also from Table 5, it was possible to plot the observable variables in two-dimensional space as shown in Figure 1. As mentioned above, EFA can group variables, so in Figure 1 the ellipses represent the groups of the observable variables with a higher correlation value with one (1) of the factors. From Figure 1, it is possible to note the interdependencies of the factors, based on the observable variables that compose them. In interdependencies, a latent variable (in our case the factors) is explained by independent variables (in our case, the observable variables).

From Table 5 it is also possible to note about the contribution of each of the A, G and I TH axes considering all 76 variables. Factor 1 has 17.1% of A, and 6.6% of G and I; Factor 2 has 18.4% of A, 7.9% of G and 2.6% of I; Factor 3 has 2.6% of G and 17.1% of I; Factor 4 has 17.1% of A and 1.3% of G; Factors 5 and 6 have only 1.3% of A.

Figure 1 - Plotting the observable variables in two-dimensional space, the axes are the principal component and the position of each observable variable and given by the correlation of the observable variables with the respective factors: (a) Plot of Principal Component 1 (relating to 36.334% of the data) versus Principal Component 2 (22.719% of the data); (b) Principal Component 2 (22.719% of the data) versus Principal Component 3 (18.303% of the data).



(a)



(b)

Source: Prepared by the authors in SPSS™.

In Table 6, we used the highest Pearson's correlation (for the values highlighted in Table 5) to establish the interdependencies, so that the observable variables were grouped in each factor. In this way, it was possible to perceive that the observable variables dealing with the faculty were grouped in Factor 2; while those describing the students were present in Factor 1, Factor 2 and Factor 5. Observable variables dealing with the research environment can be observed in Factor 1, Factor 2 and Factor 4.

Paper publications were present in Factor 2 and Factor 4. Patents filed and granted are present in Factor 1, Factor 4 and Factor 6. Interactions between universities and government are present in Factor 1, Factor 2, Factor 3 and Factor 4. Interactions between universities and industry grants can be observed in Factor 1, Factor 3 and Factor 6. In Table 6, it can be seen that most of the observable variables are correlated with the first four (4) factors. Regarding the fifth and sixth factors, only one (1) observable variable from academy showed greater correlation with each of them.

Table 6 – Observable variables with the highest Pearson's correlation for each of the factors extracted from EFA.

Factor 1	Factor 2
Observable variables	Observable variables
Number of patents granted	Number of research groups on the CNPq Lattes Platform
Number of patents granted in Brazil	Number of researchers
Number of patents granted in other countries	Number of PhDs involved in research groups
Student to PhD professor ratio	Number of professors
Number of research groups per professor	Number of PhD professors
Number of research groups per PhD professor	Number of students
Number of research groups per student	Number of undergraduate students
Percentage of PhDs involved in research groups	Number of graduate students

Researchers per number of research groups	Number of master's students
Public funding per professor	Number of PhD students
Public funding per PhD professor	Number of papers published
Public funding per student	Number of patents filed in other countries
Public funding per research groups	Number of technology transfer agreement
Public funding per researcher	Public funding
Number of patents granted per number of patents filed	Public funding received through CAPES
Number of patents granted in Brazil per number of patents filed in Brazil	Public funding received through FINEP
Number of patents granted in other countries per number of patents filed in other countries	Public funding received through the state foundations
Percentage of patents granted in other countries per number of patents granted	Public funding per patents filed
Number of technology transfer agreement per professor	Percentage of patents filed in Brazil per number of patents filed
Number of technology transfer agreement per PhD professor	Percentage of patents filed in other countries per number of patents filed
Number of technology transfer agreement per student	Number of technology transfer agreement per patents filed
Number of technology transfer agreement per number of research groups	Public funding per money generated from technology transfer
Number of technology transfer agreement per researchers	
Factor 3	**Factor 4**
Observable variables	Observable variables
Number of innovation projects in cooperation with third parties	Number of patents filed
Money generated from technology transfer	Number of patents filed in Brazil
Public funding received through CNPq	PhDs involved in research groups per research group
Number of innovation projects in cooperation per professor	Number of papers published per professor
Number of innovation projects in cooperation per PhD professor	Number of papers published per PhD professor
Number of innovation projects in cooperation per student	Number of papers published per student
Number of innovation projects in cooperation per research group	Number of papers published per research group
Number of innovation projects in cooperation per researcher	Number of papers published per researcher
Public funding per number of technology transfer agreement	Public funding per paper published
Money generated from technology transfer per professor	Number of patents filed per professor
Money generated from technology transfer per PhD professor	Number of patents filed per PhD professor
Money generated from technology transfer per student	Number of patents filed per student
Money generated from technology transfer per number of research groups	Number of patents filed per research group

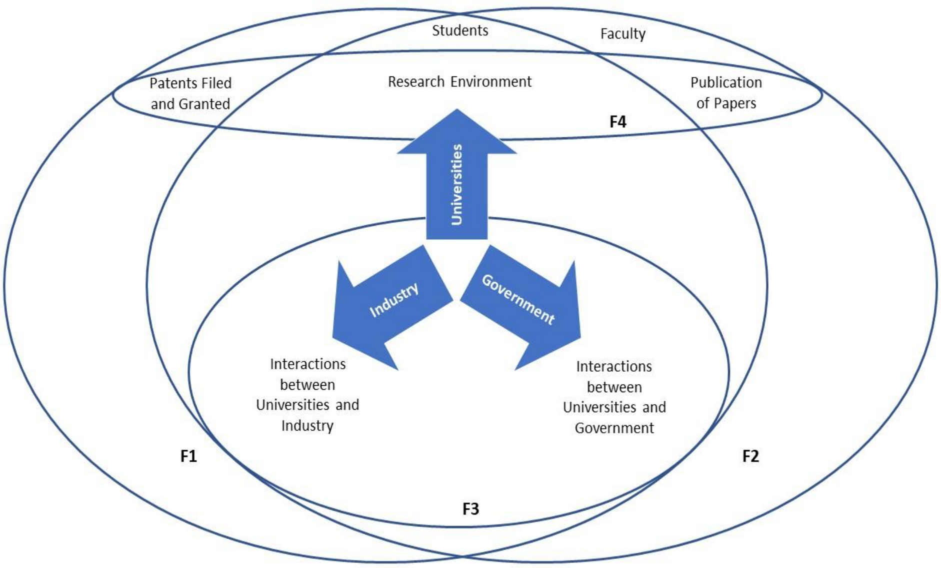
Money generated from technology transfer per researchers	Number of patents filed per researchers
Money generated from technology transfer per number of technology transfer agreement	
Factor 5	**Factor 6**
Observable variables	Observable variables
Student to professor ratio	Percentage of patents granted in Brazil per number of patents granted

Source: Prepared by the authors.

DISCUSSION

It should be noted that Brazilian public universities are far from uniform in their contribution to technological innovation. Their profiles, that is, the patterns of effort and performance over the period analyzed, are characterized by 76 observable variables. The interdependencies from the EFA results shown in Table 5, Table 6 and Figure 1 allowed the construction of the Figure 2, a framework that includes Factor 1, Factor 2, Factor 3 and Factor 4. As shown in Table 2, the shared variance for the formation of these four (4) factors is 91.637%, also a significant value for the dimensional reduction of the dataset, so we treat dimensions five (Factor 5) and six (Factor 6) as residual variation. The interdependencies of the two observable variables that originally grouped in Factors 5 and 6 were determined based on the second highest Pearson's correlation (PEARSON, 1901).

Figure 2 – Framework construction with observable variables. The construction of the framework takes into account the set theory and the EFA and shows the contributions of Brazilian public universities to technological innovation in the context of the TH.



Source: Prepared by the authors.

The TH model thus serves as a starting point for the design of Figure 2. In addition, it was possible to notice in Figure 2 (as well as Figure 1) shows the interdependencies of the factors based on the observable variables that make them up. The observable variables describing the interaction of universities with other actors (industry and government) in the TH model showed the highest Pearson's correlation between the observable variables and Factors 1, 2, and 3, according to Table 6. It was found that TH, in this context, is described by the interdependencies of these three factors.

Observable variables describing faculty, according to Table 6, showed the highest Pearson's correlation between the observable variables and Factor 2. Observable variables describing students showed the highest Pearson's correlation between them and Factors 1 and 2. The observable variables describing the research environment showed the highest Pearson's correlation between the observable variables and the Factors 1, 2 and 4. The observable variables describing the publication of papers showed the highest Pearson's correlation between the observable variables and the Factors 1 and 4. Finally, the observable variables describing patents filed and granted showed the highest Pearson's correlation between the observable variables and the Factors 1 and 4.

In their comparative analysis of European countries in innovation, Mejlgaard *et al.* (2019) also identified a variety of interdependencies, and the authors compared this analysis to an umbrella. Therefore, our results confirm the perspective of Mejlgaard *et al.* (2019). Interdependencies promote the understanding that innovation is not a linear process, but the result of a complex set of relationships between the actors involved in the production, distribution and application of different types of knowledge. From these interdependencies, which are of different types and not exclusive, it is possible to foster the cooperation necessary for innovation.

The interdependencies here are a significant theoretical contribution to studies of technological innovation, as they help to understand how different dimensions of university performance in the TH model (described by 76 observable variables) promote technological innovation activities. Figures 1 and 2 show that internal characteristics of institutions and interactions with other actors of technological innovation are inextricably linked. In the Brazilian case, the present work confirms that these actors do not act in isolation but are part of a complex system that involves other actors. Thus, it is confirmed that Brazilian public universities act in technological innovation independently and interdependently, simultaneously, as defended by Etzkowitz and Leydesdorff (1997) in the TH model.

The framework in Figure 2 allowed the comparison of the Brazilian reality with other countries. In Malaysia, Muhamad *et al.* (2021) analyzed whether university expenditure (UE), human capital (HC), and knowledge exploration (KE) impacts on communities' aggregate income (AI), quality of life (QOL), and business growth (BG) in surrounding communities. Their results showed that UE and KE positively influenced AI, QOL, and BG, but HC negatively influenced these variables. In Indonesia, the study of Fitriani *et al.* (2019) showed that there were 37 critical success factors of the TH model for SMEs. In Brazil, according to the EFA results, these correlations are not so simple. Table 5 shows that all the observable variables were correlated with all the factors. This becomes mathematically complex when considering 76 observable variables, that's why the factors from the framework in Figure 2 become so relevant. It can be argued that Figure 2 represents how Brazilian public universities are inserted in technological innovation in the light of TH.

The results of Lerman *et al.* (2021) confirmed the need for strong TH involvement in RES development in Germany. Their results showed that while government and industry act systemically, universities had only fragmentary evidence of association with the generation and diffusion of knowledge for technological innovation. Furthermore, they showed that industry plays an important role in creating innovation policies for RES, while universities seem to contribute only to policies related to knowledge generation and transfer.

According to Lerman *et al.* (2021), in the context of economically developed countries like Germany, universities tend to be limited to their knowledge role and have less influence on economic policy mechanisms such as those related to collaborative private–public systems and local factors. In Thailand, which is a developing country like Brazil, Ueasangkomsate and Jangkot (2019) highlight that collaboration with TH actors was not as high. They did not find a significant relationship between SME collaboration with universities and innovation performance.

In line with Ueasangkomsate and Jangkot (2019) and Lerman *et al.* (2021), from at the interdependencies between Factors 1, 2 and 4, we found that for the Brazilian context, from 2008 to 2015, the role of universities in technological innovation is still limited to the generation and dissemination of knowledge. Considering the interdependencies in Factors 1, 2 and 4, the main interaction between universities and the government in Brazil is through the search for funding, likewise, the interactions of universities with industry were sporadic and limited. It was not possible to observe capable interrelationships in the sense that one TH actor assumed the role of the other. Remembering that TH defends (ETZKOWITZ, 2013; ETZKOWITZ; ZHOU, 2017) that it is possible for an institutional sphere to play multiple roles without degrading or compromising its original role.

In Poland, Bieliński and Tomczyńska (2019) argued that even in the very recent development of policies to strengthen links between universities and companies, it is interesting to observe that the normative structure of science also includes researchers belonging to the ethos of industrial science. This finding indicates the willingness of many scientists to collaborate with companies. However, the lack of interest in technological innovation on the part of Polish scientists is cited by decision-makers as one of the reasons for the low level of innovation in Poland. In Brazil, the interdependencies between Factors 2 and 4 are in line with Basso *et al.* (2021), Andrade *et al.* (2022) and Sakashita *et al.* (2023), that many of the efforts of universities are not specifically aimed at developing technological innovation, but at the expense of new research that improves the publication of papers. The interdependencies between Factors 1 and 4 show that research results ultimately generate assets that are subject to patent applications and grants, with an uncertain future for absorption by the market.

According to Mendoza *et al.* (2020), faculty in the United States have a similar view of knowledge that is aligned with industrial logic when research is patentable. Interestingly, technology transfer through patenting and licensing was not part of this overarching cultural factor. Rather, these are seen more as individual entrepreneurial activities that benefit individual faculty but not industry as a whole. Only in these cases did they observe financial rewards motivating faculty to disclose to the University's Technology Transfer Office. The findings of Mendoza *et al.* (2020) indicate a preconceived notion that patenting and licensing interfere with publication and academic freedom, and that faculty who have worked in industry prior to their academic appointment have fewer publications. Another possible bias is that faculty in this study may view ties to industry as detrimental to student progress, basic science training, and socialization into the academic culture.

Our methodology differs from that of Mendoza *et al.* (2020) and Sakashita *et al.* (2023), whose studies are based on the opinion of respondents. However, it is important to highlight from the interdependencies of Factor 2 that these faculty preconceived notions of faculty are a reality in Brazilian public universities, that patenting hinders basic research, including discovery, verification and understanding. In Brazil, it is common sense that there is still a gap between science and technological innovation. In line with Cross *et al.* (2017) and De Oliveira *et al.* (2022), the interdependencies between Factors 1, 2 and 4 show that Brazil has stood out as a generator of scientific knowledge in recent years. The research environment of Brazilian public universities is largely responsible for the publication of papers. However, as mentioned above, this knowledge is only moderately reflected in the country's technological innovation. Therefore, the idea that patenting interferes with publication and basic research is a preconceived notion among those who are unfamiliar with TH theory.

In general, it is not common to include observable variables describing university students in studies of technological innovation. Ueasangkomsate and Jangkot (2019) investigate whether SMEs received support and assistance from university faculty, experts or students, understanding that students are important collaborators along with faculty and researchers.

Mendoza *et al.* (2020) highlighted that there is another way of transferring knowledge to society, in addition to the industry, which is through student entrepreneurship. However, they found that this aspect was not significant in the faculty responses in the results of their study. They attributed this faculty perception to the preconceived notion that faculty in this study see links with industry engagement of students' progress, training in basic science, and socialization to the academic culture.

Our results, presented in Table 3, show that all the observable variables of students have a commonality above 0.9. This confirms that students are important for the technological innovation activities developed in Brazilian universities. From Figure 2, the interdependencies between Factors 1 and 2 are in line with Ueasangkomsate and Jangkot (2019); we realized that students are part of the staff of these institutions and collaborate with faculties in innovation activities. Moreover, in recent years, many Brazilian universities have been involved in the creation of employment opportunities for their students, leveraging the creation of university spin-offs and the development of students' entrepreneurial mindset, which is an important aspect of local conditions for development.

The combination of our findings with previous research in Brazil, (DALMARCO, *et al.*, 2018; DALMARCO, *et al.*, 2019; MIKOSZ *et al.*, 2018, FISCHER *et al.*, 2019; DUDIN *et al.*, 2020; BASSO *et al.*, 2021; DE OLIVEIRA *et al.*, 2022; GRAEF *et al.*, 2022; ANDRADE *et al.*, 2022; ANDRADE *et al.*, 2023; SAKASHITA *et al.*, 2023) on the contribution of universities to technological innovation suggests that the TH model should focus on a dynamic system of mutual support among TH actors that can benefit all. In the present case, it is up to all universities to improve their internal capacities and become more responsive in the generation and diffusion of knowledge and technology for technological innovation.

Above all, it is necessary to go beyond this and promote a closer relationship between universities and industry, as well as the Brazilian government, in order to jointly develop policies to promote technological innovation with a view to regional and national economic and social development. Such policies must be able to improve the distribution of public resources to finance scientific and technological research. They must also be able to promote organizational entrepreneurship by improving the capabilities of existing companies and facilitating new technology-based businesses, such as incubation, start-ups and spin-offs. For example, Fitriani *et al.* (2019) show that the consistency of advisory support from the university to SMEs over a relatively long period of time was a significant factor in the development of SMEs. Similarly, Ueasangkomsate and Jangkot (2019) argued that universities should improve their collaboration with SMEs to understand their needs.

In this way, interdependencies can even help to overcome the barriers highlighted by De Oliveira *et al.* (2022) and Nascimento *et al.* (2022) and the obstacles listed by Ribeiro and Nagano (2023) and Athayde *et al.* (2022). The interdependencies also support the perspective of Dalmarco *et al.* (2018), Mikosz *et al.* (2018), Graef *et al.* (2022), Andrade *et al.* (2023) and Sakashita *et al.* (2023) that in the TH model the three actors (university, industry and government) are transformed not only internally but also through the mutual influence of the three helixes. Thus, we can argue that the trilateral collaboration between university, industry and government is essential to create a favorable environment and stimulate technological innovation in Brazil.

CONCLUSION

The comparative analysis presented and based on EFA correspond to a simple proposal to understand and visualize such complex data, associating many variables, parameters and/or dimensions. There have been previous studies considering EFA, but in this work is presented a new approach that overcomes some limitations when considering such tool separately, mapping TH in an integrative manner.

In particular, the helixes of the TH are visible and also grouped considering such statistical tools that take into account the interrelationships between academia, industry and government of Brazilian universities. In agreement with previous findings, and considering only observable variables, the TH axes were split into 55.3% for academy, 26.3% for industry and 18.4% for government, showing that there are more academy issues when considering the TH model from these eight Brazilian universities.

Considering the works of authors such as Bieliński and Tomczyńska (2019), Fitriani *et al.* (2019), Ueasangkomsate and Jangkot (2019), Mendoza *et al.* (2020), Lerman *et al.* (2021), and Muhamad *et al.* (2021), in addition to the methodological differences already mentioned, our research allowed the construction of a framework with the emergence of EFA analysis. We did not use previously established constructs; the factors emerged from the dimensionality reduction of the original data. Figure 2 was constructed from the Pearson's correlation between the observable variables and the factors.

For the EFA analysis, the medians of 76 observable variables were used from official data published by eight Brazilian public universities. In terms of EFA, based on statistical procedures taking into account the official data published by the universities, six (6) latent factors emerged, grouping these 76 observable variables according to the Pearson's correlation, representing almost 99% of the data variance, and showing a significant dimensional reduction. The first three (3) factors alone represent a cumulative percentage of 77.356%. These results showed a theoretical agreement with TH, which is a metaphor for understanding and analyzing innovation systems. One way to perceive this perspective is in line with TH, which proposes interactions between university, industry and government as essential for innovation actions, in which the interdependencies between these three (3) actors stand out, but at the same time leave the necessary independence.

Another contribution is the representation of these interdependencies, that is, how different dimensions of university performance promote technological innovation activities in the TH model. This allowed for a better understanding of the relationships between TH actors and brought the possibility of comparing the Brazilian university context with other countries. In this way, it becomes possible to identify gaps in Brazil in order to jointly develop policies to promote technological innovation with a view to regional and possibly national developments.

It was found an intrinsically intertwined system involving endogenous university issues in regional and national contexts, associated with external interactions with other TH actors, which could be represented through mathematical and statistical language. Interdependencies promote the understanding that Brazilian public universities act independently and interdependently in the technological innovation process to promote the cooperation necessary for technological innovation. It was also possible to warn that the contribution of these institutions to the process of technological innovation can be more proactive and more aligned with TH theory.

We found that the main interaction between universities and the government, in Brazil is through the search for financing. Brazilian Universities act in technological innovation independently and interdependently, simultaneously, but the interactions with industry were sporadic and limited. It was not possible to observe capable interrelationships in the sense that one TH actor assumed the role of another. Thus, universities presented only fragmentary evidence of association with the generation and diffusion of knowledge for technological innovation.

Considering the scenario revealed by the results of the EFA analysis, some possible actions are: increasing the number of patents; promoting technology transfer; seeking more interactions with industry through collaborative innovation projects; increasing technology transfer and licensing agreements; fostering entrepreneurship through new technology-based businesses, such as incubation, start-ups and spin-offs; developing an entrepreneurial mindset among students; improving the distribution of public resources to finance scientific and technological research. Above all, it is necessary to go further and promote a closer relationship between universities and industry, as well as the Brazilian government, to jointly develop policies to promote technological innovation with a view to regional and national economic and social development.

Therefore, this approach can, therefore, be used as an analytical tool and as an inspiration to guide the management of ST&I in universities and to propose technological innovation policies that take into account the three actors. In fact, a complex system such as the TH model could be illustrated by simple maps showing the interrelationships between industry, academia and government. Another contribution of this work favors the discussion of public policies aimed at promoting partnerships.

The EFA results can be applied to other institutional realities and even to other countries. As an exploratory analysis, each context should reveal a different reality, but comparisons are possible, as shown in the discussion section. A great advantage of this research is that it does not start from established constructs. In fact, the present work allowed to present the reality of the contribution of Brazilian public universities to technological innovation in the light of the TH theory.

It is important to mention that the results must also be examined in the light of the limitations of this work, especially those related to exploratory analyses, which do not have a predictive character. Future research could consider larger databases to investigate other Brazilian universities and, eventually, other institutions and countries.

Finally, it is worth mentioning that this study does not exhaust the conceptual terrain of the current and emerging theme, namely: the contribution is the statistical/mathematical quantitative approach that can add to the clarification, compared to the more traditional and classical qualitative analyses of studies on technological innovation. This is a new possibility capable of minimizing some subjectivities in the classification of innovation, especially in universities and research centers.

Contribuições das Universidades Brasileiras para a Inovação Tecnológica: uma Análise Exploratória Multivariada

RESUMO

O objetivo deste trabalho é utilizar uma abordagem quantitativa, com base em uma técnica exploratória multivariada conhecida como Análise Fatorial Exploratória (AFE), para caracterizar o comportamento dinâmico das universidades públicas brasileiras relevantes para a inovação tecnológica no contexto da Hélice Tríplice (HT). Dados de 76 variáveis observáveis, entre os anos de 2008 e 2015, foram incluídos na análise. Os resultados da AFE, baseados em procedimentos estatísticos que levaram em consideração dados oficiais, reduziram o número de variáveis, revelando seis (6) fatores latentes de acordo com a correlação de Pearson, representando quase 99% da variância dos dados. Essa redução de dimensionalidade mostra que as características internas das instituições e as interações com outros atores da HT (indústria e governo) estão intrinsecamente interligadas e podem ser mapeadas. As interdependências de fatores promoveram o entendimento de que as universidades públicas brasileiras atuam de forma independente e interdependente para fomentar a cooperação necessária à inovação tecnológica. As interdependências, quando analisadas sob a luz da HT, permitiram a construção de um framework que permitiu identificar as particularidades do caso brasileiro e compará-las com a realidade de outros países como Malásia, Indonésia, Alemanha, Tailândia, Polônia e Estados Unidos. Dessa forma, tornou-se possível identificar lacunas no Brasil que, se devidamente exploradas, serão oportunidades de desenvolvimento econômico e social regional e nacional. Especificamente para as universidades, notou-se a contribuição dessas instituições para o processo de inovação tecnológica pode ser mais proativa e alinhada com a HT.

PALAVRAS-CHAVE: Inovação tecnológica. Hélice Tríplice. Universidades. Análise Fatorial Exploratória.

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