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The classification of public research organizations: Taxonomical explorations

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Abstract

This article addresses, conceptually and empirically, the classification of public research organizations (PROs) understood as non-university and non-enterprise research-focused organizations that are public by nature or in which the government has an influence. The construction of archetypes of research performing organizations has been a standard method of analysis, as reflected in the Frascati Manual that guides national statistical offices to delineate the perimeter of the institutional sector of PROs. However, this practice has often overlooked the emergence of new types because traditional approaches to classification tend to characterize previously defined mutually exclusive categories, rather than allow evidence to reveal categories *ex-post*. This gives rise to a number of concerns related to the scientific validity of the classification of entities in the organizational field of research. The present article discusses conceptual and methodological issues associated with different classificatory strategies. It also presents the empirical results of a taxonomical exploration that allows the identification of categories not determined *ex-ante*. Our empirical strategy consists in applying clustering techniques on a number of organizational dimensions, chosen based on theoretical grounds and proxied by variables determined by data availability. We implement it on a pilot dataset of 197 research-focused organizations from eight different European countries.

Key words: public research sector; classification strategies; public research organizations; research institutes; government laboratories; hybrid research centres; research councils

1. Introduction

The purpose of this article is to analyse and classify organizations that have research and development (R&D) as their main activity. We focus on a heterogeneous group of entities, which are neither firms nor higher education institutions. The aim of this article is to discuss the conceptual and methodological issues related to different classificatory strategies of a population of research organizations outside the university and enterprise sector, either under government control or in which governments have significant influence; we call the population of interest public research organizations (PROs).[1] We also test a taxonomical approach for a sample of 197 of them in eight different European countries.

Our target population comprises autonomous research organizations, which can fall under our label of PROs. In our group of interest we include a variety of cases, ranging from multidisciplinary and complex organizations such as the *Max-Planck-Gesellschaft* (MPG) in Germany (DE), the *Consejo Superior de Investigaciones Cientificas* (CSIC) in Spain (ES), or the *Consiglio Nazionale delle Ricerche* (CNR) in Italy (IT); to organizations specialized in scientific or technological domains such as the *Netherlands Cancer Institute* (NKI), the *Centro de Regulación Genómica* in ES, or the *Institut National de la Recherche Agronomique* in France (FR). But we also include more service-oriented R&D organizations such as TNO in the Netherlands (NL), SINTEF in Norway (NO), VTT in

Finland, or FhG in DE. Under the classification criteria of official R&D statistics, these organizations would be allocated to different institutional sectors. Including all of them under the same category we could analyse their differences and similarities, and the changing boundaries between institutional sectors.

Categorization and classification are basic activities in our thinking, perception, and action (Lakoff 1987); these activities are prior to any attempt at quantification or measurement (Bowker and Star 1999) and have significant consequences because they structure our judgement (Desrosières 2015), they affect our behaviour (Espeland 2015), and over time, they become tools of governance (Rottenburg and Merry 2015).

Moreover, the classification of kinds is a necessary step in the development of systematic knowledge. The construction of comprehensive theoretical systems is only possible after a preliminary classification; the history of science repeatedly confirms that categorization is a prerequisite for the construction of far-reaching theories (Nagel 1961). Classification is an essential part of the research activity; it may make crucial contributions to diverse analytical tasks such as forming and refining concepts, extracting underlying dimensions, creating categories for classification, and measuring and sorting cases (Collier, Laporte and Seawright 2012).

Our contribution in this article is to approach the issue of categorization and classification of PROs in a novel way, avoiding folk theories where entities are positioned in well-defined kinds, are characterized by shared properties and there is only one correct taxonomy of the kinds (Lakoff 1987). Instead, we will allow the properties of the different kinds emerge from the empirical reality. We believe this method is better suited to account for the transformation that the research organizations have experienced in the last decades.

Since 1963, the Frascati Manual (OECD 2015) has set a standard for classifying research entities by institutional sectors;[2] this approach was consistent with its initial objective, namely to measure R&D activities at the national level and to allow for comparison between sectors and countries.

In the last 50 years, however, R&D systems, sectors, and the nature of organizations performing research have changed radically. The share of government funding and the balance between public and private performance of R&D activities has transformed. In most countries, the direct performance of the government sector has been reduced; for instance, in the EU-28, the share of the government sector in total R&D fell from 17% in 1995 to 11% in 2017 (OECD 2019). Do these facts and trends mean that governments have lost ground and weight in the R&D system? Official statistics on R&D expenditure appear to indicate so, but the increasing role of competitive R&D funding (Lepori et al. 2007) and the new forms of public intervention for steering research (e.g. Larédo and Mustar 2004) may suggest that modes of government intervention may have changed instead of decreased. Whichever the case, these analyses are incomplete because they do not address the changes in the R&D organizations controlled or influenced by the government.

Indeed, the last decades have witnessed important changes resulting from the transformation of the nature and functioning of research performing organizations and the blurring of boundaries across sectors and organizations. For instance, within universities, research institutes have become more differentiated (Ikenberry and Friedman 1972; Moe 1983) and autonomous (Geiger 1990). Hospitals and clinical research have become more important in the understanding of changes in the production of scientific knowledge in the health domain (Hicks and Katz 1996). New institutional logics and legitimate models of research entities have been consolidated (Cruz-Castro and Sanz-Menéndez 2007). Some technology institutes and university cooperative research centres have become linked to and even integrated with industrial research (Barge-Gil and Modrego-Rico 2008; Boardman and Gray 2010). Specialized research organizations have become a new model to produce and provide knowledge to the business sector (Preissl 2006; Sharif and Baark 2011), as well as part of a third sector of R&D (Hallonsten 2017). Finally, new hybrid (HYB) organizational forms have been identified (Sanz-Menéndez and Cruz-Castro 2010; Gulbrandsen 2011; Kosar 2011). All these organizational changes highlight the limitations of the dominant sector-based approaches to the classification of research organizations and raise doubts about their ability to reflect these transformations, to properly characterize them and to monitor changes in the role of government in R&D. The traditional classificatory approach is ill-suited to reveal the new forms of government intervention, and more importantly, the transformation of research performing organizations, mainly because it does not allow for analysing and comparing the commonalities and differences among types of PROs, that according to the Frascati Manual decision tree are 'assigned' to different institutional sectors.

New challenges emerge for any attempt of classification, especially when the starting point is the statistical unit: the research organization. With this goal in mind, we shall discuss the conceptual and methodological issues related to different strategies for classification and test an empirical approach to develop a taxonomy of PROs using a pilot dataset of 197 research organizations in eight European countries.

In this context, some attempts have been previously made to classify PROs using ideal types (e.g. Sanz-Menéndez et al. 2011). Here, we will complement this previous approach with an empirically oriented taxonomical effort. This article does not present a typology, but a taxonomy of PROs. In contrast with *typology*, the term *taxonomy* implies that the classification is based upon dimensions that are measurable and empirically established; in other words, the categories or types will be derived from empirical data of the real organizations rather than postulated *a priori*.

This article has two main parts. The first part addresses the conceptual debates and reviews previous categorization and classificatory efforts, while the second reports on a test to construct a taxonomy of PROs. This article is organized as follows. In Section 2, we define the concepts and we review the analytical approaches to categorization and classification. Section 3 discusses previous contributions to the identification of types of PROs. Based on the assessment of previous efforts, some of the methodological challenges to improve the classifications are identified in Section 4. Section 5 presents our data and empirical strategy for the construction of a taxonomy based on emerging attributes and Section 6 presents the main results. Finally, we draw some empirical conclusions, raise methodological issues, acknowledge some caveats, and identify future research lines.

2. Conceptualization and categorization

R&D activities are always performed in organizational contexts (Lambright and Teich 1981). For the purpose of this research, our focus is on what we have called PROs, but given the lack of conceptual clarity and the use of polysemic labels it is important to advance some definitions and conceptual clarifications.

An organization is 'a social unit of people that is structured and managed to meet a need or to pursue collective goals' (Scott 1998/1981). R&D is defined as the 'creative and systematic work undertaken in order to increase the stock of knowledge—including knowledge of humankind, culture, and society—and to devise new applications of available knowledge' (OECD 2015). Our operational definition considers research organizations as entities able to make autonomous decisions and allocate resources and budgets in the development of their R&D activities.

Our interest lies in organizations whose main activity is research[3] and are influenced by governments[4] to different degrees, and which can be categorized as PROs. We operationally delimit our perimeter as comprising a heterogeneous set of entities (or statistical units) whose principal mission and activity is the performance of R&D activities and in which governments have significant influence through ownership, control, or funding; regardless of their legal status. From this perspective, the term PRO is used to refer to a heterogeneous group of research performing organizations with varying degrees of *publicness* (Sanz-Menéndez et al. 2011). Nonetheless, scholars have labelled the population or some subgroups in many different ways such as research centres, research institutes, government laboratories (GOLs), technology centres, research and technology organizations (RTOs), etc.

Since our principal objective is to taxonomically classify PROs, explaining the difference between typologies and taxonomies is pertinent at this point. Hempel (1965) used the term taxonomy to refer to the theory and practice of classification, and this latter term to refer to the activity of classifying objects according to a scheme. Thus, classification in general is understood as the ordering of entities into groups or classes on the basis of their similarity. In common language, organized systems of types or classes are called typologies. However, more recently methodologists have usually considered that there are two basic approaches to classification, one more closely related to theory, concepts, and categories and another resulting from empirically derived classifications of objects (Bailey 1994; Smith 2002).

The first approach leads to the construction of what we have called typologies, and the key characteristic of a typology is that its dimensions represent concepts rather than empirical cases (Bailey 1994). Despite some critical appreciation of typologies as scientific instruments, conceptual typologies can make significant contributions to the formation of concepts (Collier, Laporte and Seawright 2012). Nonetheless, we cannot forget that while the principal scientific justification for developing classifications is that they are heuristic, because they raise the question of how the perceived order has arisen (Sokal 1974), it is important to note that a typology should be used mainly if it can be justified on empirical grounds.

The second approach to classification leads to the construction of taxonomies (McKelvey 1982), which differ from typologies in that they classify items on the basis of empirically observable and measurable characteristics (Bailey 1994). In practice, a taxonomy is *the selection of a certain number of combinations of groups of variables*; this selection may be more or less explicit, more or less valid, and more or less based on data provided by empirical research. As a summary, typologies are selected sectors of this property space which arise through a variety of procedures called *reduction* (Lazarsfeld and Barton 1951). In the general approach to classification, and statistically speaking, the dominant procedures for reduction seek to minimize within-group variance and maximize between-group variance.[5]

Although typologies and taxonomies are intellectually different modes of classification, in practice some researchers combine them in order to understand the empirical world. They first construct typologies or ideal types and then attempt to ascertain how their cases match the expected results.

In the next section, we revise previous efforts made to develop typologies and taxonomies of Public Research Organizations (PROs).

3. Previous classifications of PROs

Firms and higher education organizations have been extensively studied, but the government R&D sector and the PROs have attracted less attention and analysis. One of the main reasons of the limited conceptual clarity around PROs is that most of the literature has used some popular categorization or variations of the Frascati Manual. In practice, sometimes organizations in various institutional sectors have been combined or partitioned without clear rules; for example, it has been quite common to define categories such as *public sector research*, *public research sector*, and *public research systems* (Potì and Reale 2000; Senker 2001, 2006) in very general terms (just in opposition to the business sector), including higher education institutions—even private—and the government sector. Moreover, structural features related to their principal mission and other factors have been disregarded or overlooked; for example, other literature has indistinctively used labels such as *GOLs*, *PROs*, or *public research institutes* (OECD 1989, 2011) while keeping a closer association with the traditional definition of government sector, but sometimes including important variations too (Marcson 1972). Additionally, the dominant classificatory approach has relied on categories determined *ex-ante*.

The compounded effect of these shortcomings in the literature is that, so far, we have largely missed the opportunity to understand the emergence of new organizational forms and to map the heterogeneity among the PROs themselves. However, it is fair to acknowledge that some previous research has tried to go beyond the basic classificatory idea of the government sector and attempted to monitor emerging changes. These works have followed typological and taxonomical approaches and even a combination of both.

For example, Sanz-Menéndez et al. (2011), Cruz-Castro, Jonkers and Sanz-Menéndez (2015), and Zacharewicz, Sanz-Menéndez and Jonkers (2017) developed a multidimensional typology of research organizations, combining two basic criteria or dimensions to define ideal types of research organizations. They identified two principal attributes of research organizations likely to condition R&D activities: (1) the degree of external autonomy and resource dependence of the organization—for instance in terms of funding, human resources, and access to external knowledge—and the extent of managerial independence and discretion over resources and (2) the type of internal authority structure which characterizes the functioning of the organization, and more precisely the relationship between research professionals and the management of their organization.[6] In summary, the two dimensions in their typology were the organizational dependence of the environment, on the one hand, and the relative authority of the manager of the organizations versus the researchers/employees on the other.

Based on those features, they distinguish four ideal types of PROs: mission-oriented centres with the role to provide knowledge and technological capabilities to support policymaking. In turn, public research centres and councils (PRCs) are comprehensive institutions performing basic and applied research in several fields. Independent research institutes are publicly supported institutes performing both basic and applied research focused on issues or problems rather than fields. And research and technology organizations (RTOs) that pursue research of interest for industry (Sanz-Menéndez et al. 2011).[7]

This typology highlights the main features or the variables necessary to understand behaviour but sometimes, when applying the *ex-ante* classification, empirical cases do not fit expectations correctly, due to the complexity of transforming concepts into indicators for measuring attributes. While ideal types may help to improve conceptualizations, they may encounter difficulties of measurement when confronted with existing data. In fact, Sanz-Menéndez et al. did not attempt to empirically measure the attributes used in the definition of the ideal types. Instead, by including examples of real cases that fitted in different types, they skipped the need to develop an empirical approach based on measurable dimensions; this is precisely what we will do in this article by developing a taxonomy of empirical cases.

Other previous research has often taken a pragmatic approach to the combination of typologies and taxonomies. Michael Crow and Barry Bozeman (Crow and Bozeman 1987a,b, 1998; Bozeman and Crow 1990) construct first a multidimensional typology and second a taxonomy. They attempt to distance themselves from the traditional focus on the ownership or legal status of research organizations. They use two principal dimensions: government influence (mainly in terms of funding) and market influence (the type of technology or specialization shapes the degree of private appropriability of the technology). Their work in advancing the construction of typologies was related to the concept of publicness to assess the influence of government on organizations (Bozeman 1987; Bozeman and Bretschneider 1994; Rainey and Bozeman 2000). Crow and Bozeman have developed an 'environmental taxonomy' to capture the diversity of research organizations and to overcome some of the limitations of the classical sector-based framework. The taxonomy was a nine-cell construct (the classificatory categories) which analysed what they called laboratories according to their levels of government and market influence, with public science displaying high government and low market influence, and private technology showing low government and high market influence; almost 700 US research organizations were classified according to these influences.

Cruz-Castro, Sanz-Menéndez and Martínez (2012) also applied similar ideas to Spanish research organizations, by analysing two groups of research institutes (based on differentiated ownership) and using their funding portfolios (sources and size) to assess the influence of external actors. The result is a taxonomy in which R&D centres are located empirically; their work confirms that the positions of some research organizations in the cells do not correspond with the expectations emerging from classical sectorial divisions, based simply on ownership and control. The positioning of the centres in the bi-dimensional space reveals a much more complex characterization, one that is also related to the mission and type of research activities developed.

There are other taxonomical approaches, even among the classics. For instance, Cole (1979) analysed the different research environments related to organizational forms, in academia and other institutional arrangements; his approach preserved the institutional sectors but assigned research units to an empirical category of the classification. He proposed a two-way cross-classification of research units based on two dimensions, namely, scientific field and type of organization (university, academies of science, government, and industry). In his view, the resulting categories would show differences in three related areas: research orientation, research output, and research settings, the latter referring principally to patterns of influences regarding research priorities. The primary distinction in the resulting typology was the organizational setting.

Wilts (2000) developed a one-dimensional typology of research organizations based on their responsiveness to external goal settings, channelled through funding; he empirically illustrated the types with cases of organizations performing economic research in DE in the university and non-university sectors. And Sanz-Menéndez and Cruz-Castro (2003) analysed the PROs—understood as a population of research councils (RECs) and mission-oriented institutes—organizational response to changes in the funding environment.

From a historical perspective, Van Rooij (2011) has developed an empirical taxonomy of research organizations (he calls them laboratories), based on the three different types of knowledge production. He combines three dimensions: the type of knowledge production, its orientation, and its ownership. These three dimensions constitute the profile of a specific laboratory, but can also be used to construct a set of laboratory types; in addition to the archetypal laboratory types—university and R&D labs—six additional types were identified (three of them associated with industry).

Arnold, Barker and Slipersæter (2010) used the notion of 'research institutes' and classified them into three main categories: GOLs, academic institutes, and RTOs. Their classification is based on one dimension and refers to the 'principal mission' as the key criterion for constructing classes: mission-oriented research, basic science or oriented and applied research (to service industry and innovation). The OECD (2011) has also adopted this classificatory approach. The rationale behind these classifications is principally related to the importance of empirical groups and self-identification, and combines elements of history, evolution, and current features. Probably shaped by the innovation framing and the emergence of the identity of RTOs, we have also witnessed efforts to refer to the 'third sector' of R&D (Hallonsten 2017).

Finally, it is worth mentioning that some economists (e.g. Coccia 2005) have also produced taxonomies of research organizations, applying efficiency analysis to research institutes or subunits of a single Italian PRO, but such an analysis at the level of subunits will not be tackled here.

4. Methodological challenges for classification and the contribution of organization theory

Based on our revision of previous work, we believe that efforts to empirically classify research organizations following traditional *ex-ante* classifications raise some challenges.

The top-down *a priori* selection of categories may be particularly ill-suited to capture new or emergent organizational forms under the influence of governments but with different organizational configurations, for example, new types of research organizations in the 'Pasteur quadrant' (Martínez, Azagra-Caro and Maraut 2013) or the so-called RTOs (Preissl 2006; Leijten 2007) due to the institutionalization and taken-for-granted classification systems.

A priori classifications were criticized quite early in organization theory (Pugh, Hickson and Hinings 1969; McKelvey 1975, 1978,

1982) because they were based on broad generalizations derived from common knowledge and common sense and made little concession to empirical complexities. Moreover, very often, existing approaches to the classification of research organizations are based mainly on the intuitions of experts (Arnold, Barker and Slipersæter 2010), rather than on statistical models and procedures or sound classificatory strategies.[8]

At the same time there is a long tradition in organizational studies of developing methods to produce taxonomies of organizational types and practices, and some of these approaches could be characterized as *a posteriori*, allowing salient categories of organizations to emerge from detailed information on activities, structures, membership, or expressed identities. The methods traditionally used included a variety of cluster analyses (e.g. Erwin 2013).

The possibilities of traditional approaches to classification from an empirical point of view, may become limitations, if the classification itself, to meet the *mutually exclusive* and *collectively exhaustive* requirement, becomes conditional on univocally assigning an organization to a specific sector or category; additionally, work on the classification of organizations has become trapped in the conception of organizations as simple structures. However, recent research on organizations acknowledges that membership of or inclusion in categories is often fuzzy and partial, and does not conform to the strict boundaries implemented by traditional approaches to classification (for a review see Hannan 2010). This holds true especially when organizational fields exhibit flowing dynamics and audiences struggle to make sense of new organizations, as is the case of research organizations. However, in this article we will not explore this approach.

Generally speaking the efforts to classify PROs have become separated from organizational literature, which offers theoretical insights and inductive tools allowing for a better understanding of research organizations. This article tries to bring into the analysis some insights grounded in organizational theory, while still using conventional statistical approaches to identify latent structures.

Aldrich and Ruef (2006) made a useful historical reconstruction of relevant analytical dimensions taken on board by organization theory. They combined two different dimensions in the analysis: the relative objective/subjective appreciation of organizations and the delimitation of organizational boundaries (organization/environment). Based on this idea they consider four distinct perspectives to reconstruct the empirical focus of organizational theory, a perspective that may be useful for defining our organizational taxonomy: (1) internal functions, routines, and structures (*blueprints*); (2) resource niches that support an organizational form (*resource niches*); (3) claims of identity advanced by organizational leaders and members (*organizational identities*); and (4) external attributions applied to organizations by field participants and the general public (*cultural codes*).

With their historical approach, Aldrich and Ruef provide us with a set of critical dimensions to analyse organizations which in practice could help us to make sense of different attributes that are relevant to ascertain the diversity of PROs. This analytical framework helps us to highlight that in order to construct organizational classifications[9] certain structural attributes should be taken into account, as well as the ecological niche (relations with the environment) in which the research organizations operate. Individual organizations should be considered as a part of their organizational fields and populations of reference. Likewise, as recent organizational research has shown, the identities that organizations construct are essential parts to be considered when defining empirical taxonomies; it is not simply the case that organizations give themselves identities and cultural codes, but other actors in the same domain also provide them with a certain identity.

In what follows, we will develop a taxonomical approach for the classification a sample of European PROs; the exercise is empirical and exploratory, because we select a number of dimensions relevant to organization theory to implement a classical technique (cluster analysis) to identify *ex-post* the latent structure of the data attributes.

5. Data and methods

5.1 Data construction and descriptive statistics

For the purpose of implementing our exploratory analysis on a sample of PROs we rely on a pilot data collection strategy that ensures diversity of settings and organizations.

5.1.1 Selection of the sample

Our units of observation are entities whose main activity is to carry out research and experimental development. They are capable of decision-making with respect to the conduct of R&D with decisions ranging from the allocation of financial resources for internal or external use, to the management of R&D projects. They are also public by nature or influenced by the government either through their financial structure, their ownership, or the type of mission and vision established in their statutes. This definition lets aside Higher Education Institutions, Research Hospitals, and Business Enterprises.[10]

To guarantee diversity in the selection of our sample of PROs within countries we combine three main criteria that relate with the different ways of measuring outcomes and organizational performance: size and importance of centres in terms of number of publications, patent applications, and EU funded R&D projects.[11] In this way, we identify, at least, the most important research centres in each of the countries considered. The combination of these three different sources also enables us to avoid biases towards a specific type of organization (too close to either basic research or to industrial development).[12] To ensure that we include the largest PROs from each of the countries considered, our selection has been complemented with information from policy reports and web directories, mainly from the ERAWATCH information systems[13] and the existing associations of Research Organizations all over Europe[14] (see Supplementary Table S1).

The final dataset includes information on 197 PROs in eight different European countries: Austria (AT), FR, DE, IT, NL, NO, Poland (PL), and ES (see Supplementary Table S2 for the country distribution and Table S3 for the list of cases). The reasons for the selection of these countries were threefold. First, this set of countries represents a significant share of the PROs in Europe, and at the same time provides national context diversity. Second, in the majority of these countries, PROs play a relevant role in the R&D system. Finally, we chose countries with very different attributes in terms of size, for example, large countries in terms of population[15] as DE, FR, or IT, medium-size countries as ES, PL, or NL, and smaller countries as NO and AT; and geographical location in Europe. We also considered attributes related to R&D, such as the general level of expenditure[16] and the importance of the government sector in official statistics. Different political systems and policymaking traditions were also taken into account.[17]

5.1.2 Data construction

The procedure for data acquisition and processing to construct the dataset was organized in three phases: data collection, validation, and control. For each PRO included in the sample, data were obtained from institutional sources (annual reports, webpages, or financial statements of the research centres). Information from sectoral associations (e.g. EARTO) and research and innovation policy repositories (RIO, ERAWATCH, and the OECD Innovation Policy Platform, among others) complemented the data retrieved when needed. Information was gathered between November 2015 and September 2016 and the validation process lasted from September 2016 to December 2016. The year of reference for the information collected was 2013 or the nearest year available. A validation sheet was designed to verify the information.[18] Once all data validation sheets were collected, inherent data quality[19] was controlled by checking accuracy, completeness, consistency, credibility, and currentness.[20]

The classification variables of the sampled research organizations, according to the relevant theoretical dimensions, and their descriptives are summarized in Table 1. In any classificatory exercise the critical decision is to identify the elements, variables, or attributes that could be crucial for the purpose of finding similarities and identifying differences. We emphasized three *dimensions* in the previous section based on some of the approaches identified by Aldrich and Ruef (2006) distinguishing: internal institutional characteristics (G1), resource niche of each research organization (G2), and subjective claims of identity (G3). Since these selected dimensions have a theoretical character it was a challenge to identify the variables that could make the dimension operational in this first pilot exercise. However, the consequences of the allocation of a specific variable to a singular dimension are not critical, because of the type of method adopted: cluster analysis.

Within institutional characteristics (G1) we have included two classical organizational attributes: legal status and principal owner. Within the resource niche (G2) dimension we have included two organizational features that condition the relation of the organization with its environment: principal orientation in R&D and number of fields of science (FoS). Finally, associated with the identity claims (G3) we have included two variables associated with the characteristics of the organization that are quite determinant of the identity and its position versus other types of PROs: principal mission and institutional membership of an RTO association.

As shown by Cruz-Castro, Sanz-Menéndez and Martínez (2012), mission and type of research activities are relevant dimensions to capture the complex characterization of research institutes, when the aim is to go beyond sectorial divisions based only on ownership and control.

To provide some insight and examples into database content, Table 2 presents the values of the six variables retained for the analysis of five of the sampled PROs.

5.2 Methodology

The proposed methodological approach is implemented in two stages (Figure 1). First, we conduct a two-step cluster analysis to classify research organizations. Clustering is one of the most relevant unsupervised learning techniques used to discover an unknown structure in a collection of unlabelled information (Melchiorre et al. 2008).

Traditional clustering methods fall into two categories: relocation, for example, K-means is the most common one, and hierarchical. However, individually, none of these methods address the issue of determining the optimal number of groups. Besides, the results of traditional clustering methods are influenced by the size of the variables and therefore they should be applied to continuous variables. For our purpose, we will use a sequence of two-step cluster analyses. This methodology overcomes the aforementioned difficulties: continuous and categorical variables can be used together by extending the model-based distance measure used by Banfield and Raftery (1993) and automatically determines and optimal number of clusters based on the different groups of attributes, i.e. variables in G1, G2, and G3. We choose the optimal number of clusters to be automatically determined using the Schwarz' Bayesian Information Criterion.[21] The two-step algorithm group observations using an agglomerative hierarchical method based, in our case, on log-likelihood distances as the similarity measure criterion, to allow the use of both categorical and metric variables as classificatory variables.

Second, a non-parametric data mining tool termed classification or decision tree is used to confirm the adequacy of the taxonomy obtained by the cluster analysis and to explore unknown patterns or prediction rules.[22] Attewell and Monaghan (2015) highlight several advantages of decision tree models over other classification techniques: they produce more accurate predictions than traditional regressions; there are not relevant problems related to the degrees-of-freedom in the dataset, i.e. no matter the number of independent variables in the model and they are very good in analysing interactions from non-linear relations. Traditionally, decision trees have been widely used in clinical research although more and more social research is starting to use this technique to understand group formation (see, e.g. Thomas and Galambos 2004; Zengin et al. 2011; Sung Lee and Sung Lee 2014).

In our setting, the decision tree allows to predict membership of a particular case to a group and use a classification tree because the dependent variable is categorical, i.e. the results of our taxonomy of PROs.[23] We rely on the exhaustive CHAID method proposed by Biggs, Ville and Suen (1991) which performs a thorough merging and testing of predictor variables. Selection is accomplished by comparing the adjusted p-value associated with each predictor in the merging step.

6. Results

As advanced in the previous section, our empirical approach has two main objectives: first, to enrich our classificatory efforts of PROs with ideas from recent contributions from organization theory and second, to move from traditional top-down classification exercises to more exploratory analyses, to identify latent structures and the role of different variables or attributes in defining the taxonomy of organizations.

6.1 Sequential two-step cluster analysis

When attributes related to internal structural characteristics, resource niches, and claims of identity are considered, the highest value for the ratio of distance measures in the two-step cluster analysis implemented is achieved using four clusters. The size clusters obtained when all variables are considered (G1, G2, and G3) are quite homogeneous (see Table 3), varying between 21.7% and 29.1% of the cases included.[24] Table 3 also shows the clusters

Table 1. Overview and descriptives of classificatory variables

Variables	Definition/Explanation	Mean (Std.)	Frequencies
G1. Internal institutional characteristics			
Legal status			1 = 93 (47.2%)
	1 = Public		2 = 18 (9.1%)
	2 = Private		3 = 78 (39.6%)
	3 = Non-profit (NPI)		4 = 8 (4.1%)
	4 = Other		
Principal owner			1 = 114 (57.9%)
	1 = Central government		2 = 49 (24.9%)
	2 = Regional or local government		3 = 19 (9.6%)
	3 = Private company		4 = 3 (1.5%)
	4 = Higher education		5 = 5 (2.5%)
	5 = Other		m = 7 (3.6%)
G2. Resource niche of each RO			
Number of FoS	Number of sectors of research activity (FOS-2007) classification in which the PRO is involved, as a proxy of multidisciplinarity	2.22 (1.29)	1 = 68 (34.5%)
			2 = 67 (34.0%)
			3 = 34 (17.3%)
			4 = 14 (7.1%)
			5 = 7 (3.6%)
			6 = 7 (3.6%)
Principal orientation	Principal orientation of the R&D activity		1 = 84 (42.6)
	1 = Basic research		2 = 87 (44.2)
	2 = Applied research		3 = 26 (13.2)
	3 = Experimental development		
G3. Claims of identity			
Principal mission	1 = Developing knowledge		1 = 80 (40.6)
	2 = Contributing to solving public policy issues		2 = 72 (36.5)
			3 = 44 (22.3%)
	3 = Generating economic value		m = 1 (0.5%)
Association	0 = PRO does not belong to EARTO	0.12 (0.33)	0 = 173 (87.8%)
	1 = PRO belongs to EARTO		1 = 24 (12.2%)
N	197		

Table 2. Examples of research organizations, according to the variables

Dimensions	Variables	MPG (DE)	INRA (FR)	TECNALIA (ES)	ECN (NL)	NOFIMA (NO)
G1 Internal institutional characteristics	Legal status	Non-profit	Public	Non-profit	Private	Private
	Main owner	Central government	Central government	Private company	Private company	Central Government
G2 Resource niche of the organization	Number of FOS filed	Six	Four	One	Three	Four
	Main R&D orientation	Basic research	Applied research	Applied research	Experimental research	Applied research
G3 Subjective claims of identity	Main mission	Knowledge production	Problem solution	Value creation	Value creation	Knowledge production
	EARTO membership	No	No	Yes	No	Yes

Source: Authors' elaboration.

MPG, Max Planck Society for the Advancement of Science; TECNALIA, TECNALIA Research and Innovation; INRA, French National Institute for Agricultural Research; ECN, Energy Research Centre of the Netherlands, NOFIMA, Norwegian Institute of Food, Fisheries and Aquaculture Research.

obtained when only the first group of variables is considered (G1) or only the first and second group of variables (G1 and G2) are considered.

As observed in Figure 2, the most important variable for grouping cases is the main mission of the PROs, defined as part of their identity. It is followed in importance by legal status, a variable traditionally considered part of the structural characteristics of the organizations. The rest of the variables are less important in determining the classification outcome.

Table 4 shows across-cluster differences and indicates the characteristics defining each group.[25] It also presents for each cluster the percentage of the cases in the predominant variable category. For

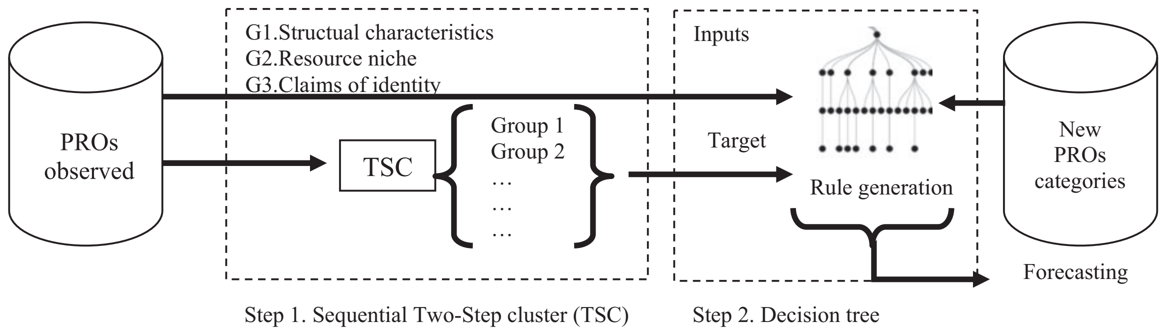

Figure 1. Empirical approach.

Table 3. Distribution of cases by clusters

	N	% of combined	% of total
Structural characteristics (G1)			
Clusters			
1	78	41.1%	39.6%
2	26	13.7%	13.2%
3	41	21.6%	20.8%
4	45	23.7%	22.8%
Combined	190	100.0%	96.4%
Excluded cases	7		3.6%
Total	197		100.0%
(G1) + Resource niche (G2)			
Clusters			
1	87	45.8%	44.2%
2	103	54.2%	52.3%
Combined	190	100.0%	96.4%
Excluded cases	7		3.6%
Total	197		100%
(G1) + (G2)+ claims of identity (G3)			
Clusters			
1	46	24.3%	23.4%
2	47	24.9%	23.9%
3	41	21.7%	20.8%
4	55	29.1%	27.9%
Combined	189	100.0%	95.9%
Excluded cases	8		4.1%
Total	197		100%

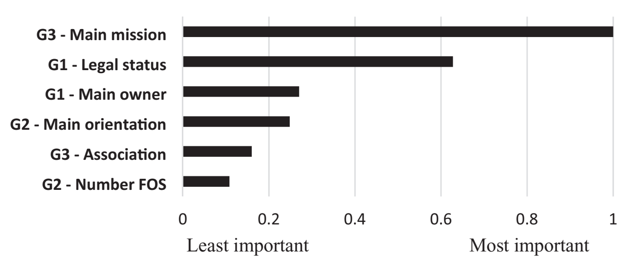

Figure 2. Predictor of importance of variables, by group.

example, in cluster 4 all cases included have defined its mission as solving public policy issues, while in cluster 1 all classified cases are non-profit institutions.

In what follows we address the classification of the sampled research-focused organizations into the different types emerging from the cluster analysis. That is to say, we define types *a posteriori*, based on the results of the exploratory taxonomical analysis described in Table 4.

Cluster 1 is composed by 46 organizations (24.3% of the sample) whose principal mission is sometimes to develop knowledge and sometimes to contribute to the resolution of public policy issues. They always adopt the legal status of a non-profit institution (100% of the 46) that involves the simultaneous control of multiple actors with an emphasis on regional governments, followed by central government. They are R&D performers which develop knowledge, with the principal focus on basic research. They generally concentrate research on one or two FoS. These attributes lead them to be considered as HYB forms. Within this cluster are organizations such as the Leibniz Institute of Plant Genetics, the Institute for Bioengineering of Catalonia, the Institute Pasteur in FR, or the NKI.

Cluster 2 comprises 47 organizations (24.9% of the total sample) which are generally public and under the principal control of the government, with an almost exclusive focus on developing knowledge (91.5% of the 47 PROs in this cluster have knowledge development as the main mission). Organizations in this group perform both basic and applied research, the last in smaller proportions. They are quite heterogeneous in terms of FoS, but all the organizations undertaking research in all the six FoS belong to this cluster. They are not part of any association of technological centres, and within this group we find institutions that have traditionally been known as RECs or Academic Institutes, such as the Spanish National Research Council (CSIC), the National Centre for Scientific Research in FR, and the Italian Research Council (CNR).

Cluster 3 comprises 41 organizations (21.7% of the sample) which have as its main mission to generate economic value (95.1% of the 41 have it as their main mission) and tend to be non-profit institutions, sometimes even private, whose principal control is exercised by private companies. As such, their principal mission is to generate economic value. They focus on experimental development, generally limited to research in a single FoS. This profile clearly corresponds to technological institutes and almost all the sampled organizations associated with EARTO are in this cluster, despite not all of cases of this cluster are EARTO members. In this group are also to be found Tecnalia in ES, the German Centre for Artificial Intelligence in DE, or Joanneum Research in AT.

Finally, cluster 4 comprises 55 public organizations (29.1% of the sample) that are generally under the control of central governments. This is a characteristic shared with cluster 2. However, in this case, they focus on contributing to the resolution of public policy issues. Basically, they develop applied research activities and are quite heterogeneous regarding the number of FoS. Examples of these

Table 4. Cluster differences and distribution of PROs

Variables	Clusters (% PROs)			
	Cluster 1 24.3% (46)	Cluster 2 24.9% (47)	Cluster 3 21.7% (41)	Cluster 4 29.1 (55)
Principal mission (G3)	Knowledge development 67.4%	Knowledge development 91.5%	Generation of economic value 95.1%	Contribution to solving public policy issues 100%
Legal status (G1)	Non-profit institutions 100%	Public 72.3%	Non-profit institutions 61%	Public 98.2%
Principal owner (G1)	Regional-local government 58.7%	Central government 78.7%	Private company 36.6%	Central government 92.7%
Principal orientation (G2)	Basic research 60.9%	Basic research 59.6%	Economic development 51.2%	Applied research 56.4%
Association (G3)	No 97.8%	No 93.6%	No 56.1%	No 96.4%
Number of FOS (G2)	2 50%	1 31.9%	1 43.9%	3 29.1%

Table 5. Emerging types of PROs. Results of our taxonomy

	Cluster 1 Hybrids HYB	Cluster 2 Research councils REC	Cluster 3 Technology and innovation centres TIC	Cluster 4 Government laboratories GOL
Principal mission	Develop knowledge	Develop knowledge	Generate economic value	Contribute to solve public policy issues
Legal status	Non-profit institution	Public	Non-profit institution	Public
Principal owner	Regional governments	Central government	Private companies	Central government
Orientation of R&D activity	Basic/applied research	Basic/applied research	Experimental development	Applied research
Association RTOs	No	No	Yes	No
Multiple FoS	Yes	Yes	No	Yes

classical GOLs are organizations such as the Norwegian Institute of Food, Fisheries and Aquaculture Research or the Centre for Energy, Environmental and Technological Research in ES.

As we already said in Section 3, the types defined by Sanz-Menéndez et al. (2011) resulted from an ideal type construction; however, their labelling was done using existing empirical groups, as in the case of RTOs and that could create some confusion. The taxonomy presented in this article follows an empirical approach to the classification of PROs, based on their structural characteristics, resource niche, and identity claims. We therefore label the types of organizations differently: HYBs, RECs, Technology and Innovation Centres (TICs), and GOLs. In Table 5, we include a summary of the main empirical characteristics of each group.

While the above results are derived from a small sample of representative cases in eight European countries, the potential implications of this empirical approach go beyond descriptive features of resulting types, since such approach could also be tested as a predictive tool.

6.2 Exhaustive CHAID decision tree

The second stage of our empirical strategy is to test the classificatory power of the clustering method by using a non-parametric technique, a classification tree, in which target values are the results from the taxonomy and the input variables are those used in the cluster analysis. All the variables which were significantly different between PRO types are considered as input variables (Supplementary Table S4). Decision-tree modelling uses splitting criteria to break a node, i.e. a test on an attribute, and form a tree structure. The goal is to reduce the impurity of nodes. Splitting criteria provide a proportion for each predictor variable. Variables that have the highest rate in the aforementioned criterion remain in the model (Tayefi et al. 2017). Seventy five percent of the total sample is used as a training set and the remaining 25% is used to evaluate the model.

Using the Chi-square statistic for selecting the variables, and pruning the final tree, we observe that out of the total of six input variables used, the decision tree is able to classify a large enough number of cases in the database with only two main variables: principal mission (G3—identity claim) and legal status (G1—structural characteristics). The final decision tree, with an accuracy of around 90%, has eight nodes and five leaves.

The variable used for branching on the first level is the principal mission, which turned out to be statistically significant at the significance level of 1%.[26] This branch resulted in three new nodes (node

1, node 2, and node 3). Node 1, based on those centres whose mission is develop knowledge, consists of 55 PROs which 27 (49.1%) are classified as HYB whereas 28 (50.9%) are claimed to be RECs. Therefore, this node is not conclusive and needs further splitting to reach a clearer classification. Likewise, node 3 classifies, based on the mission ‘contributing to solve public policy issues’, 11 (22%) PROs as HYBs and 38 (76%) as GOLs, respectively, out of a total of 49 PROs. On the contrary, node 2 represents a final node or leave and only with the variable main mission, specifically the category ‘generate economic value’ is able to classify correctly 31 out of 33 PROs (95.9%) as TICs.

The variable legal status was then used for branching on the second level. According to Supplementary Figure S1, branching resulted in four new nodes with two of them (node 4 and node 5) coming out from node 1 and two of them (node 6 and node 7) from node 3. Both processes are statistically significant.[27] Node 4 includes the 55 PROs from node 1. Based on legal status those classified as non-profit institutions would represent in its whole HYBs (27 PROs) while, in node 5, if the PROs shows other type of legal status, they would be classified as RECs (28 PROs). Finally, node 6 consists of 37 PROs classified 100% as GOLs according to their public legal status while node 7 includes a higher variety of PROs. However, based on a non-profit legal status, node 7 is able to classify correctly 84.6% of the cases (11 PROs out of 13) as HYBs.

To sum up, the tree shows that in a subgroup whose principal mission is to generate economic value, the probability of being a TIC is 93.9%. In the subgroup whose principal main mission is to develop knowledge and the legal status is NPI, the probability of being an HYB reaches 100%. Within the group of centres whose principal mission is to develop new knowledge, those whose legal status is other than NPI are all RECs. When the principal mission is to resolve public policy issues and the legal status is public, all of the centres in the tree are GOLs. However, if their legal status is NPI, the probability of being an HYB reaches 84.6% (Supplementary Figure S1).

The evaluation of the tree for the testing and training datasets is shown in Supplementary Table S5. The classification table compares the observed and the predicted PROs types. Using the training sample and a testing sample, the percentage of correctly classified cases varies from 97.1% in the training sample to 90.2% in the testing sample. Then, out of 138 cases in the training sample, 134 were correctly classified while in the testing sample the total number of cases correctly classified was 46 out of 51. The number of correctly classified cases is therefore more than acceptable, with a risk of 0.029 (0.014) and 0.098 (0.042) in the training and in the testing sample, respectively.

Therefore, it can be concluded that the decision tree represents a supportive instrument for the classification of different types of PROs. The information derived from the classificatory decision tree is useful in a context in which boundaries between public and private organizations are increasingly blurred. Our cluster analysis and the decision tree represent the first attempt to empirically complement, with a taxonomical approach, previous efforts developed mainly based on expert assessment (Arnold, Barker and Slipersæter 2010) or on ideal types (Sanz-Menéndez et al. 2011).

7. Discussion and conclusions

The traditional division among institutional sectors makes the understanding of the internal heterogeneity of PROs difficult. Besides, it has limitations to assess the diversity within the population of PROs and to monitor the influence of governments on those organizations. This situation makes necessary further studies to explain the inner nature of this type of research organizations. To cover this gap in literature, the objective of this article has been to better understand different forms of organizations by implementing empirically a taxonomical approach for the analysis of PROs. The motivation was also related to the need to complement the way in which the R&D statistics are developed.

On the analytical side, we aim to contribute to some longstanding open questions: what are organizational entities (Freeman 1978)? How to decide whether an organizational form has been adequately described? What characteristics should be used? Are certain characteristics more important than others?

This article has also contributed to the improvement of the PROs concept construction and also to the empirical categorization and perimeter definition. Instead of classifying research organizations based on *ex-ante* decisions, we have explored the latent structures emerging from some of the key organizational attributes. We have allowed the data to produce the relevant categories in the taxonomy. As we have seen, this classificatory approach could also be of interest to advance conceptualization, by testing the adjustment of the empirical reality to existing typologies.

Inspired by certain approaches of organization theory, we have also improved the selection of the relevant dimensions for classification; however, the proxies used to reflect the different dimensions could be enlarged in further work, as could the number of cases.[28] As regards the relation of our findings to the literature the taxonomic use of the three underlying dimensions of organizations identified on the historical trajectory of organizational theory (Aldrich and Ruef 2006), and their operationalization trough six different variables, has generated a fourfold classification of our sample of 197 PROs in Europe. Each type of PROs was associated with a typical pattern of contextual variables, from which occurrence may be predicted. The analysis has confirmed that some of the assumptions of previous theoretical classificatory approaches cannot be taken for granted. Even if we assume that our three dimensions and six variables are interrelated, and they present some regularities; we cannot assume that these interrelationships reflect a complete one-to-one interdependence of aspects, or a linear connection between variables and classes, as the traditional *ex-ante* classifications of types suggest.

Methodologically, we have tested an *ex-post* approach to construct a taxonomy of PROs that may overcome some drawbacks of previous *ex-ante* and *expert-based* classifications. Previous literature has pointed out the limitations of organizational typologies for empirical research. Constructing typologies could be of use for concept construction, but the main caveat is that these typologies largely ignore important variability among organizations. The main added value of our taxonomical approach (even if in our pilot has only taken on board a few variables) is that it allows for a more refined account of diversity and heterogeneity, and that new variables, if needed, can be added as they become empirically available.

The use of a taxonomical approach with empirical basis, as we have done in this article, is helpful in various dimensions: (1) it simplifies the summary of complex underlying patterns; (2) it refines hypotheses on the evolution of the populations; (3) it aids in the analysis of the validity and utility of the typologies based on ideal types; and (4) it could serve, with longitudinal data, as a basis for predicting organizational change in populations of PROs.

From the policy side, the main implication relates to the constant need for better and more accurate descriptions of the clients/objects of policies and interventions in a context of blurring boundaries between sectors, partnerships, and the emergence of HYBs and new types of centres. Our cluster analysis has produced an empirical taxonomy of PROs and allowed us to describe the principal attributes for each type of organization. This result is useful to support policymakers in establishing adequate R&D policies taking diversity into account, as well as tailor-made evaluation systems for PROs in the current context. The taxonomical approach can be used as a mapping tool of the PRO population in particular areas or regions, so as to improve knowledge of the empirical reality before or during policy design.

We have found some empirical regularities in the types of PROs resulting from the empirical taxonomy. For instance, RECs and GOLs tend to be the largest organizations in the population of PROs, while TICs and HYBs the smallest. Central government exerts direct power through ownership in RECs and GOLs, while regional governments, private companies, and higher education institutions have an important role in TICs and also in some HYBs. The last two are principally focused on applied research and basic research, respectively, in the fields of engineering and natural sciences and sometimes in health too.

We have tested the classificatory power and potential of our taxonomy through an exhaustive CHAID classification tree. This type of classification technique has fewer limitations in terms of the type of variables included in the analysis than other type of techniques. Accordingly, the decision tree represents an adequate tool for the classification of new centres into the different empirical categories of research organizations.

Some limitations of our work should be mentioned, as they suggest fruitful avenues for further research. We are aware that the sample selection procedure can generate some biases in our data. These caveats may pose limitations for the generalizability of the statistical results. However, the conceptual framework and the methods are replicable and they open new approaches for analysing PROs empirically. Another potential problem is related to the degree of sensitivity of the resulting classification. As reported, various additional tests have been developed, such as comparing results with a different number of clusters.

Some challenges remain: the traditional approach to classification based on mutually exclusive and collectively exhaustive categories is still very common. Further study should find ways to deal with the problem of potential multiple memberships of different categories in some of the empirical cases. A solution also needs to be found to the challenge of unclear boundaries in some of the categories and their dimensions. New methodological approaches could be used to address one limitation of traditional classificatory attempts, namely Qualitative Comparative Analysis, in connection with the implementation of fuzzy set logics. Alternatively, LDA (Latent Dirichlet Allocations) procedures could be used to deal with the challenges of classification. More practical work should be performed to improve comparability between the Frascati Manual and our approach; we should test how the sample of cases is allocated among the different institutional sectors. In this regard, as a scalability exercise, future research may explore the classificatory power on the set of PROs included in ORGREG if information is available.

In this article, we have advanced mainly in the analysis of organizational differences: the study of differences among the forms of organizational populations and the recognition and classification of important differences. Next steps relate to the need to address how and why the differences come about. Some years ago a key question was posed: why are there so many different kinds of organizations? (Hannan and Freeman 1977: 936).

We know, as Campbell (1965) suggested, that diverse environmental conditions foster diverse paths of evolutionary change; he recommended researchers not to focus on the direction of the evolution, but rather on the underlying process of variation and selective retention. The analysis of the factors that give rise to identifiable organizational types and the forces that maintain boundaries among the different organizational types over time are relevant questions for further work.

Supplementary data

Supplementary data are available at *Research Evaluation Journal* online.

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Notes

1. Some scholars have labelled this population of organizations as ‘research institutes’ (Gulbrandsen 2011) and/or the ‘third sector’ (Hallonsten 2017), but their population boundaries could differ. Both authors aim to study a diffuse residual sector of research organizations that are neither properly higher education, firms nor private non-profit entities. In that respect, the subject matter is similar to ours, but we prefer to abstract from using those labels to our population of interest. Both studies present examples of organizations included in our population, and Hallonsten provides a detailed analysis of three Nordic technical research institutes, as examples of the ‘third sector’, but none of them analyses the whole population in detail. For these reasons we prefer to use the term PROs and recall that our focus is to study their different types and heterogeneity, bottom-up, from examining the data, considering that there are emerging types that may have links with existing sectors and may not be cleanly considered a residual sector because of that.
2. The Frascati Manual established three different institutional sectors (government, higher education, and business), in which the principal differentiation factors were ownership and control; plus a residual category, related to non-profit institutions.
3. R&D may be the principal activity of the organization or simply an activity connected to its main organizational tasks. R&D is an activity performed by various kinds of organizations, including companies, higher education institutions, hospitals, museums, etc.

4. The attribute ‘public’ has been usually understood as a legal status despite the Frascati Manual insists on the principal criterion being government ‘control’. Our understanding is closer to the idea that ‘all organizations are public’ (Bozeman 1987) and is related to the concept of ‘publicness’ understood in broad terms as the level of governmental influence on their research activities and funding, rather than merely ownership.
5. Lazarsfeld (1962) put this very clearly, stating that ‘when we describe a person or a group in the course of an empirical investigation, we unavoidably use a fixed number of properties. In a formal sense these properties can be of considerable diversity: quantitative variables such as age, ranks such as position in a competitive examination, dichotomies such as sex, or even unordered classes such as country of birth. These variables form a property space, and their combinations are what today we call a Cartesian product’.
6. Recent analyses have added a basic element to the empirical characterization of public research organizations, namely funding streams. Cruz-Castro and Sanz-Menéndez (2018) have addressed the issue and have advanced several propositions regarding the influence of the different funding streams regarding authority relationships over research in PROs.
7. As in classical approaches to the construction of ideal types, the cells of the matrix define the four different types of research organizations and the classification fulfils the two main criteria that every type is in a cell and can only appear in one cell (*mutually exclusive and collectively exhaustive*).
8. The latest edition of the Frascati Manual (OECD 2015) has improved the criteria and rules for the *ex-ante* allocation of statistical units to the different institutional sectors, but a challenge remains, namely how to deal with the increasing heterogeneity among actors in the same institutional sector and the boundary blurring of existing categories.
9. This approach has also been implemented by Ruef and Nag (2015) applying these concepts to improve the taxonomies of US universities.
10. In the context of the RISIS project in which our analysis started, a complementary effort was developed to construct a directory of various types of organizations involved in R&D activities: Register of Public-Sector Organizations (ORGREG) (see, https://risis-eter.orgreg.joanneum.at/about/intro). Our definition and perimeter of Public Research Organizations include organizations classified in ORGREG under the rubric of PROs and sometimes Public Administration Organizations and/or Private Non-profit Organizations (PNP). We consider in our classification of PROs only those organizations that while their main activity is to carry out R&D, according to the Frascati definition, they are capable of decision making with respect to the conduct of R&D, the allocation of financial resources for internal or external use, and/or the management of R&D projects. This identification of the organizational level is important, and we restrict PROs to those so-called Umbrella Organizations when the organizations have a centralized decision-making governance model and to the associated organizations when they are the ones on charge of those decision-making processes. Therefore, our PRO sample will represent a subsample of the PROs included in ORGREG. Alike that platform, in our article we pay attention to the entity characteristics and not only to who controls the organization. This is the main reason why some of our PROs may be found under the rubric PNP, see, for example Institute Curie in FR. This is an example of an R&D centre managed by a private foundation without direct commercial aim but with a strong public mission that is influenced somehow by governments at different jurisdictions.
11. The selection was the result of combining the institutions allocated to the ‘Government sector’, according to the total output indicator included in the SCImago Institutions Ranking 2011, which reflects the total number of documents published in academic journals indexed in Scopus in a previous time period. A similar procedure was followed to identify the institutions with the highest number of patent applications (non-university or private firms), using data on patent applications to the European Patent Office from 2000 to 2011, as available in the Worldwide Patent Statistics database, April 2014 (PATSTAT). The selection was complemented using the EUPRO database, based on CORDIS data, to identify the institutions with an important number of EU funded research projects.
12. We acknowledge that this approach may generate other possible biases in the sample for the construction of our database. First, the presence of young centres may be underestimated, either because they are still not visible in the publication rankings or because their limited background of activity has not resulted in patents yet. Second, small centres highly specialized that may be important in certain areas of knowledge may be underrepresented. And third, research centres focused on R&D activities more related to the provision of services, rather than carrying out R&D activities resulting in traditional outputs such as patents or publications, might also be underrepresented in our sample.
13. Information Platform on European, National and Regional Research Systems and Policies.
14. Science Europe or EARTO among others.
15. Large countries in terms of population are considered those ones with a population higher than 50 million people. Medium size countries would be those ones with population levels between 10 million and 50 million people. Small countries would be those ones with less than 10 million people.
16. Leader countries as AT, DE, or NO with more than a 2% of their GDP devoted to R&D expenditures; follower countries as FR, NL, IT, or ES on the threshold between 1% and 2% and those laggards around 1% as PL.
17. The higher proportion of Spanish cases in the final sample is justified by diversity at the regional level, as Spanish regional governments have competence in the design and funding of R&D policies.
18. A datasheet was designed to collect and validate the information extracted from institutional sources. The data validations sheet templates (available under request) were sent to representatives of the selected organizations and experts in the fields. The data validation process aimed at verifying that the value of the variables collected by the researchers in charge of the data collection came from a given set of acceptable quantities. The data validation process included not only confirming but also corrective actions such as data editing or data imputation.
19. As defined by ISO 25012.
20. PRO database has been subject to an extensive data validation and quality control procedure, which has been coordinated by the Institute of Public Goods and Policies of the CSIC with the

help of native contacts in each one of the PROs analysed in the database. First, information about 100 PROs was validated by experts in NIFU (NO), Leiden University (NL), AIT (AT), and CNR (IT). Experts in CSIC validated the remaining 97. Second, information on a total of 87 PROs was validated in another stage by representatives of their own organizations.

21. This classification method uses and approach closed to BIRCH algorithm (Zhang, Ramakrishnon and Livny 1996). For more detailed information about the algorithms in the two-step cluster model, see Zhang, Ramakrishnon and Livny (1996) and Chiu et al. (2001).
22. Breiman et al. (1983) developed classification trees as non-parametric data mining tools which are not restricted to the use of specific types of variables, namely dichotomous, categorical, or continuous variables (Attewell and Monaghan 2015). One noteworthy advantage of decision tree models over other classification techniques is that they can handle smaller datasets (Markham, Mathieu and Wray 2000).
23. Another type of decision tree are regression trees where the dependent variable is continuous (Samoilenko and Osei-Bryson 2007).
24. Eight research organizations were not considered because of the lack of information in some of the classificatory variables.
25. To check the robustness of the results, we compared them using K-means clustering. After performing the necessary transformations of the variables, results were consistent with those obtained from two-step cluster analysis.
26. Chi-square = 215.603, df = 6, p-value < 0.001.
27. From node 1—Chi-square = 55.000, df = 1, p-value < 0.001 and from node 3—Chi-square = 44.939, df = 2, p-value < 0.001.
28. As mentioned before, ORGREG has constructed a Register of research entities in more countries and it could be used to replicate and enlarge the pilot work done in this article, but an adaption of the *ex-ante* classificatory labels they use will be needed.

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