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Modelling R&D and Innovation Support Systems – Analysis of Regional Cluster Structures in Innovation in Portugal

Teresa de Noronha Vaz[1]
Purificación Vicente Galindo[2]
Peter Nijkamp[3]

[1] *Faculty of Economics and Research Centre for Spatial and Organizational Dynamics (CIEO), University of the Algarve, Faro, Portugal;*
[2] *University of Salamanca, Spain, and Research Centre for Spatial and Organizational Dynamics (CIEO), University of the Algarve, Faro, Portugal;*
[3] *Faculty of Economics and Business Administration, VU University Amsterdam, and Tinbergen Institute, The Netherlands.*

Tinbergen Institute Amsterdam
Gustav Mahlerplein 117
1082 MS Amsterdam
The Netherlands
Tel.: +31(0)20 525 1600

Tinbergen Institute Rotterdam
Burg. Oudlaan 50
3062 PA Rotterdam
The Netherlands
Tel.: +31(0)10 408 8900
Fax: +31(0)10 408 9031

Duisenberg school of finance
Gustav Mahlerplein 117
1082 MS Amsterdam
The Netherlands
Tel.: +31(0)20 525 8579

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Teresa de Noronha Vaz[1], Purificación Vicente Galindo[2] and Peter Nijkamp[3]

Abstract

This paper offers a new methodology to identify R&D and innovation clusters, on the basis of a regional analysis of innovation support systems in Portugal. Using a web-based inventory of R&D and innovation agencies, an extensive data base is created. This data set is next analyzed by means of Principal Coordinates Analysis followed by a Logistic Biplot approach (leading to Voronoi mappings) in order to design a systematic typology of innovation clusters in the main regions in Portugal. A striking result is the significant difference in innovation systems at regional level in Portugal. The paper is concluded with policy recommendations.

Key words: R&D and innovation, regional innovation systems, principal coordinates analysis, logistic biplot, Voronoi mapping, public policy.

JEL: Q55, Q16

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[1] mtvaz@ualg.pt, Faculty of Economics and Research Centre for Spatial and Organizational Dynamics (CIEO), University of the Algarve, Faro, Portugal

[2] Department of Statistics, University of Salamanca, Spain, and Research Centre for Spatial and Organizational Dynamics (CIEO), University of the Algarve, Faro, Portugal

[3] Corresponding author, p.nijkamp@vu.nl, Department of Regional Economics, VU University Amsterdam, and Tinbergen Institute, The Netherlands.

1. Introduction

The institutional conditions for successful regional innovativeness are increasingly drawing scholarly attention. This study addresses the interaction between innovation support systems and entrepreneurship with a view to the improvement of regional development. Conceptually, it adopts the framework of regional (or local) innovation systems. However, it advances further in searching for a new analytical and empirical basis to identify regional innovative performance, and to investigate whether and how relevant support institutions can be pushed to favour innovations. In particular, the model employed in our study aims to assess regional/local external and internal success factors for the institutions' performance.

Despite the perceived importance of R&D and innovation strategies, it is noteworthy that, generally, in the R&D and innovation literature there is some ambiguity inherent in the measurement and modelling of the drivers and impacts of innovation. After a concise discussion of this issue, our paper proceeds by presenting an operational analytical method to empirically understand the determinants of an innovation process, based, inter alia, on Logistic Biplots. Compared to classical innovation measurement and modelling methods, its novelty is to allow the identification of the quantitative innovation profiles of appropriate support institutions, thereby demonstrating its efficiency for innovation management and assessment.

Methodologically, our empirical application is based on information obtained from observations on a sample of more than 600 Portuguese R&D and innovation institutions, randomly selected from internet sites. To construct our database, all their web-published explicit descriptions have been investigated and transformed into coded empirical attributes (such as knowledge promotion, strategic management, R&D promotion, knowledge transfer, partnership and cooperation support and governmental orientation, skills development, etc.). Next, after the application of what is called 'principal coordinates analysis', a Logistic Biplot application to these attributes allowed an exact classification of innovation profiles, and following this a Voronoi mapping approach was able to show each institution's innovative performance. This model was then applied at a regional scale in Portugal, in such a way that the regional determinants of innovative performance in the form of regional innovation patterns could also be identified.

Our analysis framework enables us to present two types of research findings: (i) a comparative analysis of the institutions' performance in different regions based on a visualized ergonomic three-dimensional view of the variables that we considered as attributes (or determinants) of innovative patterns, by region, level of importance for general R&D and innovative processes, and the relative proximity of each firm to the nearest significant determinants; and (ii) a presentation of the empirical results leading to a call for tailor-made public support actions. With a view to the most efficient use of support institutions, and given the observed highly diversified context and the multiplicity of identified institutions' innovative performance, policy makers may need to accept and integrate differentiated and distinct policy measures regarding innovation and entrepreneurship. Because of the demanding efforts required to put in practice such policy lessons, the quantitative methodology presented may provide a new and relevant contribution to regional innovation and development analysis and policy making.

2. An Exploratory Review of the Innovation Scene

2.1. Is the wish father to the thought?

Over the past decades, R&D and innovation have been recognized as a significant driver of social and economic change. Schumpeter (1934, 1954), Freeman (1987), and Fagerberg (2003), for example, have contributed to this view and explained how important it is to induce a process of socio-economic restructuring and development by means of technological change in the continuous creation of new products or processes, to be absorbed by society. Nijkamp (2009a, 2009b) and Stimson et al. (2006), for example, have consistently aimed to identify and to measure the mechanisms concerning how innovation and entrepreneurship produce socio-economic impacts at regional or local levels. Furthermore, many studies, e.g. Fischer (2006) and Stough and Nijkamp (2009), have intensively investigated the resulting spillover effects.

Clearly, many research issues concern the metrics of innovation, but any answer should in any case address the following two research questions: “How can innovation be measured?” and “Why measure it?”. It is evident that the way measurements are selected depends on the combination of the answers to these two questions. We can imagine distinct perspectives: (i) investors, executives, directors – wishing to find out the additional advantages created as a return on the investments made for a certain business goal; and (ii) policy makers, economists, social planners trying to assess the amount of effort necessary to promote further education, R&D and entrepreneurship, in order to encourage economic activity and enhance social welfare (partially or as a whole). The present research paper proposes a model that combines in a novel way both views – the institution’s (manager’s) perspective and that of the regional developer (generally, policy maker).

The previous observations may lead to concerns on how risky entrepreneurship (as a preliminary stage of innovation) and innovation itself are. Apparently, high-tech innovation (and related entrepreneurship) is more difficult to achieve and risky than innovation based on market structure requirements. However, as Drucker (2007) points out, this risk may be reduced if it is based on a *purposeful innovation* concept – an argument in favour of the previous discussion.

In order to better understand the content and scope of *purposeful innovation*, a reference to evolutionary principles may be helpful. From an evolutionary perspective, the properties of industrial dynamics have been widely explored by Winter et al. (2000). The authors searched for the consequences of an ever-lasting flow of newcomers, in other words, *firms as carriers of technological innovations* (by introducing more efficient techniques of production). In such a continuous process of change, typical of industrial dynamics and mostly driven by entrepreneurship and innovation, the authors identify some *generic* features typical of microeconomic heterogeneity: persistent fluctuations of aggregate variables such as price, production capacity, or total output; instability in market shares; and distorted size distributions of firms. The authors claim that an essential condition for *fast* industrial growth is the permanent expansion of opportunities for innovation; such *opportunities* arise from the interplay between learning possibilities and demand patterns. Thus, in order to encompass *purposeful innovation* (Drucker, 2007) at firm level, prospects for future opportunities should be continuously envisaged (Winter et al., 2000). This calls for clear call for target setting and, simultaneously, for planning innovation management and monitoring and modelling entrepreneurship/innovation, endogenous to market trends and skills development or learning.

2.2. Is change a mechanism?

Change may be considered to be a transitional mechanism in artificial and closed systems. However, the cultural, economic and environmental determinants of a modern society represent complex open systems, thus hindering clear direct cause-effect relationships. That is why, as knowledge progresses and ICT becomes more available, our research methods call for increasingly sophisticated analytical instruments to reproduce reality and to design scenarios of change, as is clear from modern complex systems models (see Reggiani and Nijkamp, 2009).

It is, therefore, not surprising that even conventional assumptions on economic change are increasingly questioned. These assumptions include: non-exogenous demand shifts and output growth because of unlimited market expansion; learning as capital efficiency; market growth caused by technical progress allowing continuous investment gains and increases in productive capacity; decreasing production costs per unit of output; increasing returns to scale; increasing risk of losing knowledge accumulation and a consequent need to increase costs in learning; learning as a interaction between demand and capital costs per unit of output, leading to an expansion of production capacity from a short-term perspective, and a long-run sustainable *system.* Yet, from a structural perspective on economic growth, there is no way to exclude the role of the past: there will normally be a *path-dependent* inertia. It is noteworthy that, within this scope of interest, the economic capacity for change (or development) makes a difference, when institutions (or firms) are closely involved with networking systems.

In effect, a great variety of studies on clustering have been *instrumental in describing how – though not so much why* – organizations and institutions get together to face and respond to competitive challenges (see, e.g., Porter 1998). Similar attempts, however, can be found to explain why different entities join efforts to collaborate (see Westlund and Bolton 2006; Putnam 2000). In a cluster, managers and decision makers share a great number of cognitive references and experiences that help to establish connections that follow the same pattern of organizational behaviour. Nonetheless, in addition to general positive economies of scope and agglomeration externalities, one may also point to negative consequences: because all actors participate in the same organizational culture, they may induce a strategic myopia to the process, thereby reinforcing imitating and non-innovative behaviours.

2.3. Is clustering a systemic process?

As mentioned above, changes in the economy, mainly resulting from innovative activities, should not be conceived of as simple mechanisms, as they take place within a broad and complex context of non-static interrelated links among actors (mostly firms) who internally tend to modify their own functions.

Porter (1990), for instance, has explained how the competitive advantage of firms is strongly predisposed by geographical proximity among business actors, promoting links and enhancing a clustering tendency. This permits positive externalities to be combined with local economic conditions to enhance internal performance and, eventually, to generate external regional advantages. Besides, it is important to note that firms are embedded in local or external networks of tradeable and untradeable commercial, marketing, knowledge, partnership and innovation relationships (see Lechner and Dowling 2003).

In more recent years, various studies have deepened our knowledge of the possible causes of clustering and its effects on spatial dynamics. For a view on the relationship between innovation and regional development, we refer to Gordon and McCann (2005), who provide an alternative view on this issue. Focusing on the role of agglomeration economies in fostering localized learning processes such as informational spillovers or other information transfers, the authors were able to identify the amount of benefits for regional localized firms resulting from the development of new products and new processes.

To enrich the debate on the spatial clustering phenomena, in the past years, the concept of Regional Innovation Systems (RIS) has been defined as a network of organizations, institutions and individuals, within which the creation, dissemination, and exploitation of new knowledge and innovation occurs (Cooke et al. 2004). The RIS concept has been introduced to describe how the industrial and institutional structure of a given national or regional economy tends to guide technological and industrial development along certain trajectories. The link between 'clusters' and 'regional innovation systems' is that, within these spatial systems, groups of similar and related firms (e.g. large and small firms, suppliers, service providers, customers, rivals, etc.) comprise the core of the cluster, while academic and research organizations, policy institutions, government authorities, financial actors and various institutions for collaboration and networks make up the innovation system of which the cluster is a part (Teigland and Schenkel 2006). It has been shown by Arthurs et al. (2009) that the patterns of close and remote relationships (including those taking place within a cluster) vary, at least, by industry, ownership status, market orientation, as well as in conformity with the growth phase and size of the cluster.

In the same vein, Davis (2008) adds a major contribution to this theoretical frame. He demonstrates that, besides the variation in the form of relationship, and even in relatively small regional innovation clusters, different *structures of interaction* and different *innovation pathways* can be detected. Taking the IT sector in New Brunswick as a case study, he was able to identify a variety of significant structural relationships, for example, with the firms that supply business services, innovation support services, investments, and business partners or with those providing local technical infrastructure and the use of public/private knowledge-based business services (Davis and Schaefer 2003).

2.4. Can innovation pathways be planned and modelled?

The consultant group GRIST, London, has published a report on the complexity of innovation performance measurements (Birchall et al. 2004). This report was one of the first responses, coming from the side of practitioners of innovation, to the solutions presented for innovation measurement and modelling. Notwithstanding the significant effort developed on the topic by researchers, policy makers and other stakeholders, most studies suggest that there remains a serious gap between what firms are hoping for and what they are receiving from their investments in innovation. The conventional approaches to performance measurements may be very useful regarding the information related to the firms' cost and efficiency, but they tend not to have a strong impact in the area of innovation management.

It seems plausible to state that innovation is intangible and, at least in part, dependent on serendipitous occurrences in the innovation environment. Consequently, the measurement of innovation performance is, despite its importance, a somewhat controversial topic that is still in its infancy. Traditional approaches to performance measurement typically inform about 'what' has happened, but do not address the 'why', thus leading many managers to view the innovation process as a 'black box' that defies rational managerial analysis.

In a similar vein, Nauwalers and Wintjes (2008) discuss the opportunity of measuring and monitoring innovation policy in Europe. The multiplicity of indicators of innovation (Innovation Scorecards, etc.) is so broad that the resulting studies seem to have little direct impact on the policy-making community. The authors mention that the more is learnt about indicators, the higher the level of incoherence achieved. Researchers realize that much is still to be learnt on what concerns the relationship between innovation policies and innovation performances.

Clearly, the literature on the measurement and modelling of innovation is rich, but has not yet convincingly contributed to identifying the most successful ways of policy making and decision-taking processes. Recalling Schumpeter's observations on the tendency of innovations to cluster, the use of innovation as an instrument of public policy in order to promote fast economic development requires profound empirical attention. This argument has recently motivated some researchers to address more explicitly the *drivers of innovation*. Various efforts to better understand these *drivers* have stimulated researchers to adopt the resource-based view of the firm (see Vaz and Cesário 2008). These authors take for granted the heterogeneous character of firms and their unique choices related to strategic behaviour (Knudsen 1995; Kaleka 2002). In this context, knowledge is recognized as a key resource for firms and other economic agents (Albino et al. 1999; Nooteboom 1999). In addition, some authors have stressed the key role of 'good communication' between industry and research institutes for the successful transfer of technological knowledge (Kaiser 2002). An interesting extension of this literature can be found in the Triple Helix concept, whereby the triangular interaction between the research community, governments and industries is seen as key to successful innovation (see Etzkovitz and Leydesdorff 1998). Doloreaux (2002, p. 250) adds that knowledge is socially embedded, created, and reproduced through social interaction. The previous observations have led to the theoretical framing that inspired the model used in our innovation study and, in particular, the choice of the explanatory variables.

As a modest contribution to the vast state of the art, the main goal of this paper is thus to develop an appropriate tool in innovation research, so that, on the basis of a novel methodology, it is possible to identify the driving forces of innovation institutions, and to shape cluster configurations within a regional dimension. Our application will now address the Portuguese regional innovation system.

3. Empirical Database and Analysis

3.1. The database

Our investigation uses an extensive set of private institutions and public organizations located in Portugal, evaluated by their WebPage contents on innovation. The data was obtained by means of a careful observation of 820 Internet sites of Portuguese institutions, classified into different groups of actors. These sites, collected in 2006, were found by means of a random choice of a sample including all the organizational sites presenting the following keywords – *inovação*, *inovador* and *inovada/do* – on their sites. Finally, after filtering, 623 institutions could be traced and classified into nine groups, each characterized by ten variables. The selection of the variables was based on earlier developed research work (for more details, see Vaz and Nijkamp 2009 for the theoretical basis, and Galindo et al. 2010 for the measurement methods). The latter two publications suggest and identify relevant variables as plausible determining innovation indicators and patterns. In this context, Caraça et al. (2009) have recently emphasized that science is a driver for knowledge creation and therefore one of the first steps in the process for innovation. In addition, these authors clearly recognize the *multi-player* dimension of innovation and its wider institutional setting. The various variables referred to above are plausible descriptors of innovation patterns, and will, therefore, be called *attributes of innovation.* They are the following: Promoting knowledge (PK); Studying processes (SP); Managing (Mg); Promoting R&D (PRD); Knowledge transfer (KT); Support to entrepreneurship (SE); New product development (NPD); Promoting partnership and cooperation (PPC); Application of external technologies (AET); and Orientation towards innovativeness (Or).

As grouping factors in the sample, the following institutions, actors of innovation, have been considered: governmental agencies, associations, technological parks and science centres, R&D organizations, entrepreneurship support entities, technological schools, university interfaces, financial institutes – as well as venture capitalists or high risk investors and, finally, other institutions[4].

3.2. Policy relevance for Portugal

Portugal has made a significant effort to promote networking institutional systems. In particular, this was stressed for the scientific and tertiary Portuguese education – a strategic task grounded on: (i) the concept that innovation should be considered together with competence building and advanced training at the individual skills level; (ii) the need for expanding the social basis for knowledge activities; and, finally, (iii) the intensification of social networks to enlarge the mobility of users to facilitate innovation diffusion. According to Heitor and Bravo (2010), the country experienced the highest growth rate in Europe in private R&D expenditure between 2005 and 2007, jumping from 0.3 per cent of GDP, in 2005 to 0.8 per cent of GDP, in 2008, as a result of the PRIME programme – a programme that supported industrial activity in Portugal from 2000 to 2006.

In a recent study, Vicente-Galindo and Vaz (2009) investigated the degree of effectiveness of the PRIME programme at both locational and sectoral levels, by reviewing the financing of 14,910 projects granted by PRIME. Their conclusion was that PRIME has also been responsible for accentuating the socio-economic asymmetries in Portugal, thereby reducing many efforts made by the previous regional policies. In

[4] 1) Governmental agencies: all entities which pertain to the sphere of governmental power, and which exercise regulatory functions in political terms, as far as innovation is concerned. Furthermore, they play an important role in the promotion, administration, financing, and evaluation of creativity and innovation processes in the country; 2) Associations: this category includes all agencies with a legal status which, depending on the interests of their associates, influence creativity and innovation. Examples of the activities of such associative entities include: sectoral or regional cooperation, knowledge transfer management, support to value creation (e.g. certification), regional partnerships; 3) Technological parks and science centres: in this category one can find institutions which offer technical, technological or other type of support to organizations in the same economic or industrial sector. These entities contribute to creativity and innovation processes in numerous ways: technology transfer, partnerships, and certification; 4) R&D organizations: organizations which direct their main activities to R&D, and which concentrate on broad economic and industrial applications (this category does not include private and public institutions whose main activity is not R&D, though such institutions may have large investments in R&D activities); 5) Entrepreneurship support entities: this category refers to institutions or organizations which aim to stimulate creative and entrepreneurial activity; 6) Technological schools: these are concerned with entities which aim to provide technological and professional training and education in innovation-related areas; 7) University interfaces: these include structures, units, or university associations, operating in a particular university, and which aim to act as an interface between the university and private and public institutions; 8) Institutions: these are public and private organizations involved in innovation and/or with investments in innovation activity. 9) Financial institutes, as well as venture capitalists or high risk investors have also been classified in this category; 10) Other: these are other entities with a role in creativity and innovation and which have not been included in any of the previous categories.

any case, Portugal may be seen as a rich laboratory in which to observe regional innovation patterns, their drivers and their likely future evolution.

3.3. The regional perspective

A main goal of this paper is to identify and map out the innovation institutions in Portugal in geometric space, based on each individual innovative performance. However, because the institutions' geographical location leads them to act distinctly, a further research question is raised: What is the institutions' associated behaviour? And is there a regional pattern to be found? At this stage it is important to emphasize that, already quite some time ago, Posner (1961), Krugman (1979) and Fagerberg (1987, 1988) argued that in cross-country or cross-regional analyses, the presence or lack of innovation may 'affect differential growth rates'. In particular, an imitative or innovative modus operandi may explain different levels of development among countries or regions, for example, the 'technology gap' or even the 'north-south' asymmetry.

In order to respond to such questions, the model developed by us was applied at a regional level. In our database, a filter of the whole sample allowed the institutions to be grouped by region. The model application was able to detect regional innovation patterns or, in other words, the way the various attributes integrated in geographical space were able to identify and represent *regional structures of innovation*.

The five NUTS-II Portuguese regions were used for our analytical purposes: Norte; Lisboa and Vale do Tejo; Centro; Alentejo; and Algarve (see Figure 1).

Figure 1: NUTS-II classification for Portugal

3.4 Methodology and practical interpretation rules

The information for our statistical model is organized in an I x J binary data matrix obtained from several innovation attributes, in which the I rows correspond to 623 entities or units (18 Governmental entities, 297 Companies, 70 Associations, 20 Technological parks and centres, 58 R&D organizations, 48 Entrepreneurship support entities, 12 Technological schools, 80 University interfaces, and 14 Other entities), and the J columns to 10 binary innovation attributes coded as present (1) or absent (0), (comprising Promoting knowledge, Studying process, Managing, Promoting R&D, Knowledge transfer, Support to entrepreneurship, New product development, Promoting partnership and cooperation, Application of external technologies, Orientation).

As a statistical tool to obtain the main innovation gradients[5], of the entities (institutions) and their relation to the observed attributes, we apply a novel algorithm, recently proposed by Demey et al. (2008) that combines Principal Coordinates Analysis (PCoA) and Logistic Regression (LR) to construct an External Logistic Biplot (ELB).

The algorithm starts with a PCoA, as a technique for ordering the units, in Euclidean space, on the latent gradients. The second step of the algorithm is applying a logistic regression model for each variable by using the latent gradients as independent variables. Geometrically, the principal coordinate scores can be represented as points on the map, and the regression coefficients are the vectors that show the directions which best predict the probability of presence of each attribute.

To search for the variables associated with the ordering obtained in PCoA, we look for the directions in the ordering diagram which best predict the probability of the presence of each unit. Consequently, the second step of the algorithm consists of adjusting a logistic regression model for each variable by using the latent gradients as independent variables. According to the geometry of the Linear Biplot for binary data (Vicente-Villardón et al. 2006), in which the responses along the dimensions are logistic (Logistic Biplots, LB), each variable is represented as a direction through the origin.

For each attribute, the ordination diagram can be divided into two separate regions predicting presence or absence, while the two regions are separated by a line that is perpendicular to the attribute vector in the Biplot and cuts the vector at the point predicting 0.5. The attributes associated with the configuration are those that predict the respective presences adequately.

Measures of the quality of the representation of units, and variables related to the graphical representation, are also calculated in this framework. The quality of representation of a unit is measured as the percentage of its variability accounted for by the reduced dimension solution, and is calculated as the squared cosine of the angle between the point/vector in the multidimensional space and its projection onto the low dimensional solution. As the representation is centred at the origin, the variability of each unit is measured by its squared distance to the centre, so that the quality of representation can be measured by the ratio between the squared distance in the reduced dimension and the squared distance in the complete space. The quality of representation of a variable is measured as a combination of three indexes: the p-value of the logistic regression, in order to test the relation of the solution and each variable (using the deviance); the Nagelkerke-R squared; and the percentage of correct classifications, using 0.5 as a cut-off point for the expected probability. As a way to identify which

[5] There are two gradients, each representing the values of the abscis and the ordinate corresponding to the geometrical location of each institution as a point in the corresponding plane. Together, they show the joint value of the determinants for each institution.

gradient (dimension) is mostly related to each variable, the cosine of the angle of the vector representing the variable and the dimension is calculated. The variable is more related to a particular gradient when the absolute value of the cosine is higher than the cosine for other gradients. Then, to produce an elegant solution, a Voronoi diagram of the geometrical relationships is presented; that is, a special decomposition of a metric space determined by distances to a specified discrete set of points: these are centroids from a k-means cluster analysis of the ELB coordinates[6].

Figure 2 shows the biplot representation of one of the variables. The small arrow is the graphical representation of the variable on the biplot and shows the direction in the space spanned by the first two dimensions that better predicts the expected probabilities projecting each unit (circles in the graph) onto that direction. All the points in the graph that predict the same probability lie on a straight line perpendicular to the prediction direction. In the graph we have identified two lines predicting probabilities of 0.5 and 0.75. The first of these lines is important, because it splits the map of points into two regions: the region predicting presence ($\pi_{ij} > 0.5$), and the region predicting absence ($\pi_{ij} < 0.5$). The coloured red circles are the regions with observed presence, and the blue circles the regions with observed absence. Note that most of the observed presences are on the region predicting presence, most of the observed absences are on the region predicting absence, and that the wrong predictions have expected probabilities close to 0.5. This means that the variable is apparently correctly summarized on the graph as shown also by the high values of the quality of the representation indexes (R2 = 0.92, with p = 0).

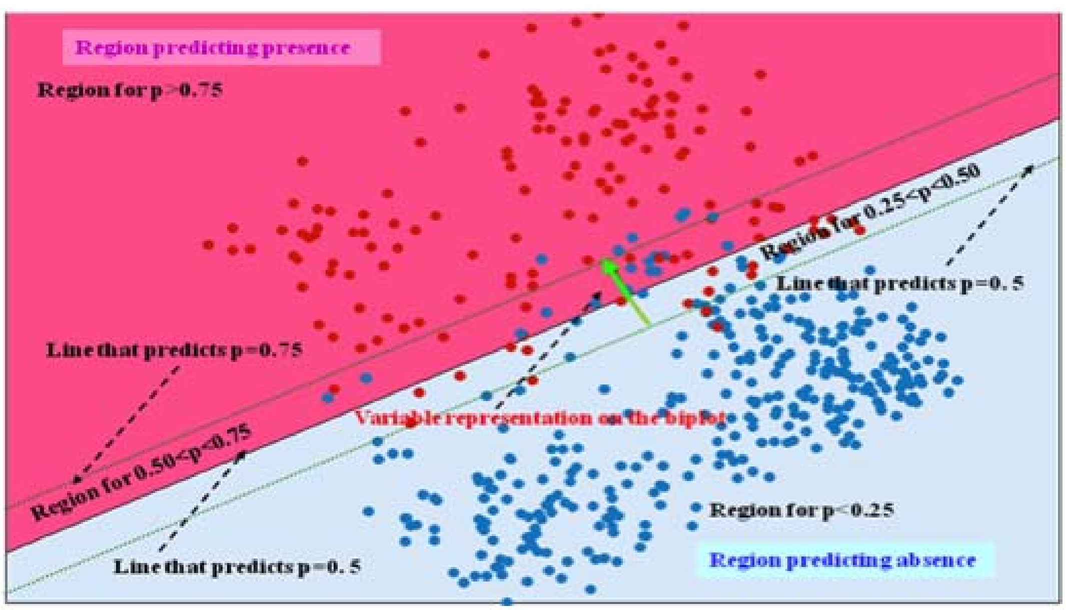

Figure 2: Interpretation of the relationship between units and variables

[6] A computer program, based on Matlab code, for implementing these methods is available and can be obtained from the website: http://biplot.usal.es.

4. Empirical Results

4.1. Graphical representation of the national determinants of innovation

Principal Coordinates Analysis (PCA) was applied to the dissimilarities matrix, based on the Russel and Rao coefficient. It produced the following results (see Table 1):

Table 1: Eigenvalues, percentage of accounted variance

Eigenvalue	% of variance	Cumulative %
37.49	57.99	57.99
6.78	10.49	68.49
5.85	9.05	77.53

The first principal plane (two-dimensional solutions) accounts for 77.53 per cent of the variability. The first eigenvalue is significantly higher than the second one, meaning that, even if the two innovation gradients are considered, the first (horizontal) dimension accounts for most of the information.

In Figure 3 below a complex representation of the patterns of the main determinants of dynamic innovation according to the ten considered variables can be observed: Promoting knowledge (PK); Studying process (SP); Managing (Mg); Promoting R&D (PRD); Knowledge transfer (KT); Support to entrepreneurship (SE); New product development (NPD); Promoting partnership and cooperation (PPC); Application of external technologies (AET); Orientation (Or). Each institution has a particular location on the graph and is represented by a different symbol. The distance between any two institutions (points of the configuration) serves to approximate, as closely as possible, the dissimilarity between them.

Each attribute is represented as a direction through the origin. The projection of a point representing a unit onto an attribute direction predicts the probability of the presence of that attribute, i.e. the expected probability of having that attribute for an entity with the same combination of variables (innovation pattern). A vector joining the points for 0.5 and 0.75 is drawn; this shows the cut-off point for the prediction of the presence and the direction of increasing probabilities. The length of the vector can be interpreted as an inverse measure of the discriminatory power of the attributes, in the sense that shorter vectors correspond to attributes that better differentiate between units. Two attributes pointing in the same direction are highly correlated, while two attributes pointing in opposite directions are negatively correlated, and two attributes forming an angle close to 90º are almost uncorrelated. The variability of each unit is measured by its squared distance to the centre.

The global goodness of fit (quality of representation) as a percentage of correct classifications in the Biplot appears to be 90.43 per cent. The goodness of fit indexes for each variable (attribute) are shown in Table 2. All R-squared values are higher than 0.6, and therefore all variables are closely related to the two dimensional PCoA solution.

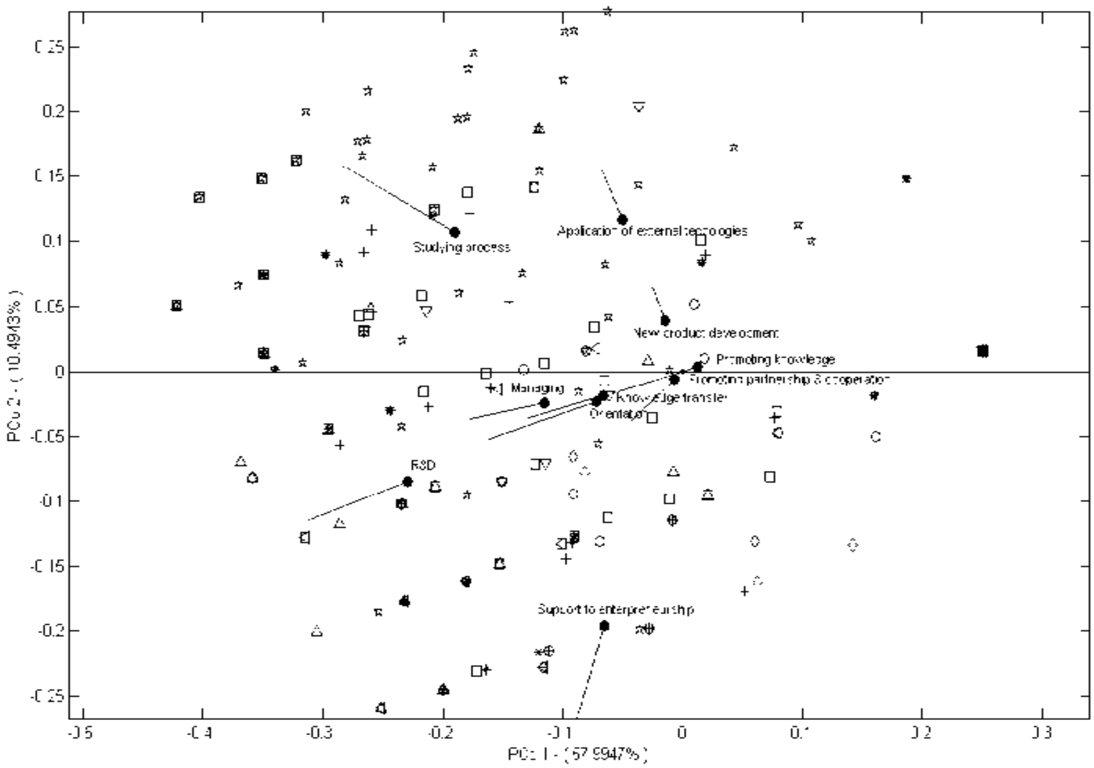

Figure 3: Determinants of innovations by attributes

Next, Table 3 contains the cosines of the angles of the variables with their respective dimensions. It has to be pointed out that any direction in the two-dimensional solution, and not just the main dimensions, can be considered as innovation gradients. The graph can help us to look for the most interpretable directions.

Table 2: Goodness-of-fit of the variables/attributes

Variable	*Deviance*	*p-value*	*R2*	*% Correct*
Promoting knowledge	674.94	<0.0001	0.88	93.42
Studying process	418.70	<0.0001	0.68	82.50
Managing	906.68	<0.0001	0.92	92.29
R&D	549.93	<0.0001	0.77	89.08
Knowledge transfer	763.53	<0.0001	0.90	92.67
Support to entrepreneurship	267.13	<0.0001	0.60	90.69
New product development	723.74	<0.0001	0.94	97.27
Promoting partnership & cooperation	733.39	<0.0001	0.92	95.19
Application of external technologies	822.17	<0.0001	0.93	95.02
Orientation	544.62	<0.0001	0.77	83.95

An analysis of the cosines' value in the graph identifies two main directions for innovation gradients. A third column has been added to Table 3 showing which variables are most related to each direction. The first gradient is almost parallel to dimension 1 (horizontal) and the second to dimension 2 (vertical). Although the variable

‘Promoting knowledge’ has a higher cosine with the first dimension, it has been assigned to the second gradient after inspecting the graph.

Table 3: Cosines of the angles

Variable	*1st grad.*	*2nd grad.*	*Associated gradient*
Promoting knowledge	0.96	0.28	1
Studying process	-0.87	0.49	2
Managing	-0.98	-0.20	1
R&D	-0.94	-0.35	1
Knowledge transfer	-0.96	-0.27	1
Support to entrepreneurship	-0.31	-0.95	2
New product development	-0.35	0.94	2
Promoting partnership & cooperation	-0.75	-0.66	1
Application of external technologies	-0.40	0.92	2
Orientation	-0.95	-0.31	1

From the graph and the quality indexes, we can conclude that the first innovation gradient is mainly represented by a combination of the following variables/attributes: Promoting knowledge (PK); Managing (Mg); Promoting R&D (PRD); Knowledge transfer (KT); Promoting partnership and cooperation (PPC); Orientation (Or).

Observing the directions of the vectors, in Figure 3, relative to the first latent attribute, it can be concluded that the presence of all those attributes tends to show up together. The graphical representation corroborates the interpretation of the innovation gradients in terms of their relations to the variables. It can also be concluded from the graph that there is a high correlation between Promoting knowledge, Studying processes, Managing, Promoting R&D, Knowledge transfer and Orientation. This is because they have small angles pointing in the same direction.

A Voronoi diagram of the geometrical relationships is represented in Figure 4[7]. By analysing our Voronoi diagram and relating it to the clusters, it is possible to find four groups of entities (institutions) with homogeneous patterns along the two gradients considered.

The 295 institutions positioned in Cluster 4 answered “NO” to all variables that concerned innovation. The 46 institutions of Cluster 1 reported the presence of all variables, except the variable Support. The 173 institutions of Cluster 2 reported a different a pattern. All of them have the presence of Promoting knowledge (PK); a high percentage have the presence Managing (Mg); and just a few of them have Promoting R&D (PRD). Cluster 3 comprises 105 institutions which have the presence of the variables Promoting knowledge (PK) and Promoting partnership and cooperation (PPC)

[7] In this case a set of points is given in the plane: the centroids from a k-means cluster analysis onto the ELB coordinates, which are the Voronoi sites. Each site has a Voronoi cell, consisting of all points closer to a centroid than to any other site. The segments of the Voronoi diagram are all the points on the plane that are equidistant to the two nearest sites. The Voronoi nodes are the points equidistant to three (or more) sites. Two points are adjacent on the convex hull if and only if their Voronoi cells share an infinitely long side.

but lack Studying process (SP), New product development (NPD), Application of external technologies (AET) and for the rest of the indexes there is no general pattern.

The entities (institutions) positioned on the left side of the graph have a higher capacity to innovate dynamically, because they tend to aggregate higher values of those variables (attributes) (Cluster 2), while the entities (institutions) positioned on the right side lack most (or all) of such attributes (Cluster 4). Using this method, the scores of the variables on the first gradient can be ordered to obtain the sequence of attributes that define the degree of innovation. The most innovative institutions have all the attributes, and then they are followed by those entities that have all of them, except Promoting R&D (PRD) whose score is situated to the left of the graph. The next group would have all the attributes, except Promoting R&D and Managing (Mg), and so on.

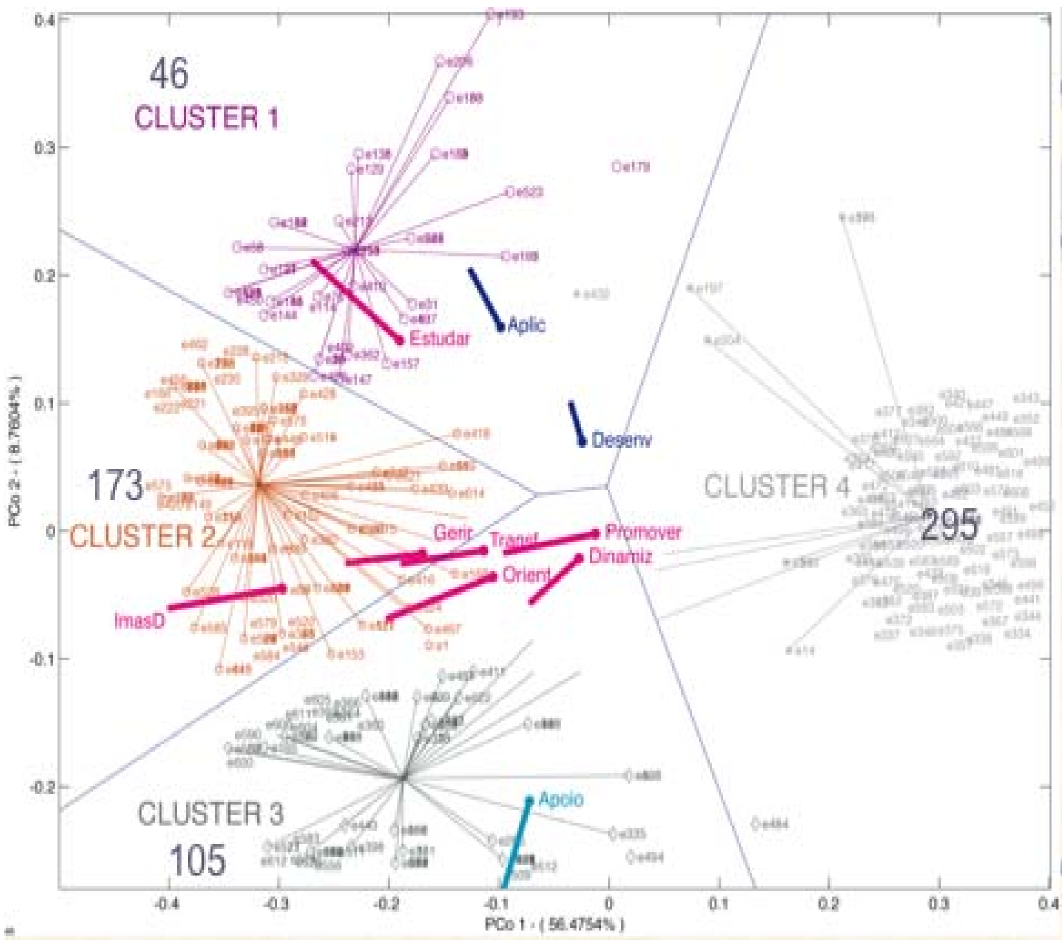

Figure 4: The structure of an innovation system with clustering effects in Portugal

The second innovation gradient is a combination of Studying process (SP); New product development (NPD); Application of external technologies (AET) pointing in the positive direction; and Support to entrepreneurship (SE) pointing in the opposite direction. This secondary gradient is not correlated with the first one and summarizes an aspect of innovation independent from the main dynamic pattern. The institutions situated on the top (Cluster 1) of the graph would combine the first three attributes listed above and the last is absent, while the institutions situated at the bottom (Cluster 3) have the last one but the first three attributes listed above are absent.

4.2. Graphical representation of the regional determinants of innovation in Portugal

After having mapped each firm's innovative performance, the same analyses may now be applied at regional level, so that the regional determinants for innovative performances as regional innovation patterns can be recognized and a comparative analysis is possible.

4.2.1. Lisboa and Vale do Tejo

The analysis for shows four clusters indicating four different innovation patterns. Cluster 4 is composed mostly of those institutions without any innovation. The remaining three clusters are composed of those institutions that innovate (higher gradient of innovation), but for each cluster the attributes appear to combine differently (see Table 4). In our table PRESENCE means that in this percentage of institutions the indexes of innovation that are mentioned were present. For example, for the first case, the innovation index PK was present in 98.24 per cent of the institutions studied. The same occurs with ABSENCE: for example, 22 per cent of the institutions studied had no Support to entrepreneurship (SE). In this case, the goodness of the fit is minimal for the attribute Support to entrepreneurship (SE) – $R^2 = 0.16$ – no discriminatory capacity at all. Thus the following graphic representation includes the other nine attributes, for which R^2 varies between 0.74 and 0.93.

Table 4: Innovation clusters for Lisboa and Vale do Tejo

Cluster 1: 57 institutions (21.19%)

Presence of	*Absence of*
Promoting knowledge (PK) 98.24% New product development (NPD) 98.24% New product development (NPD) 98.24% Knowledge transfer (KT) 92.98% Orientation (Or) 92.98% Promoting partnership and cooperation (PPC) 87.71% Managing (Mg) 84.21% Studying process (SP) 80.70% Promoting R&D (PRD) 50.87%	Support to entrepreneurship (SE) 22%

Cluster 2: 64 institutions (23.79%)

Presence of	*Absence of*
Knowledge transfer (KT) 100% Managing (Mg) 92.18% Promoting knowledge (PK) 92.18% Promoting R&D (PRD) 64.06% Orientation (Or) 56,25%	New product development (NPD) 29.6% Support to entrepreneurship (SE) 14.06%

Cluster 3: 43 institutions (15.95%)

Presence of	*Absence of*
Promoting knowledge (PK) 70.96% Promoting partnership and cooperation (PPC) 67.44% Orientation (Or) 58.14% Knowledge transfer (KT) 51.6%	New product development (NPD) 37.20% Support to entrepreneurship (SE) 32.55% Managing (Mg) 27.90 Studying process (SP) 23.25%

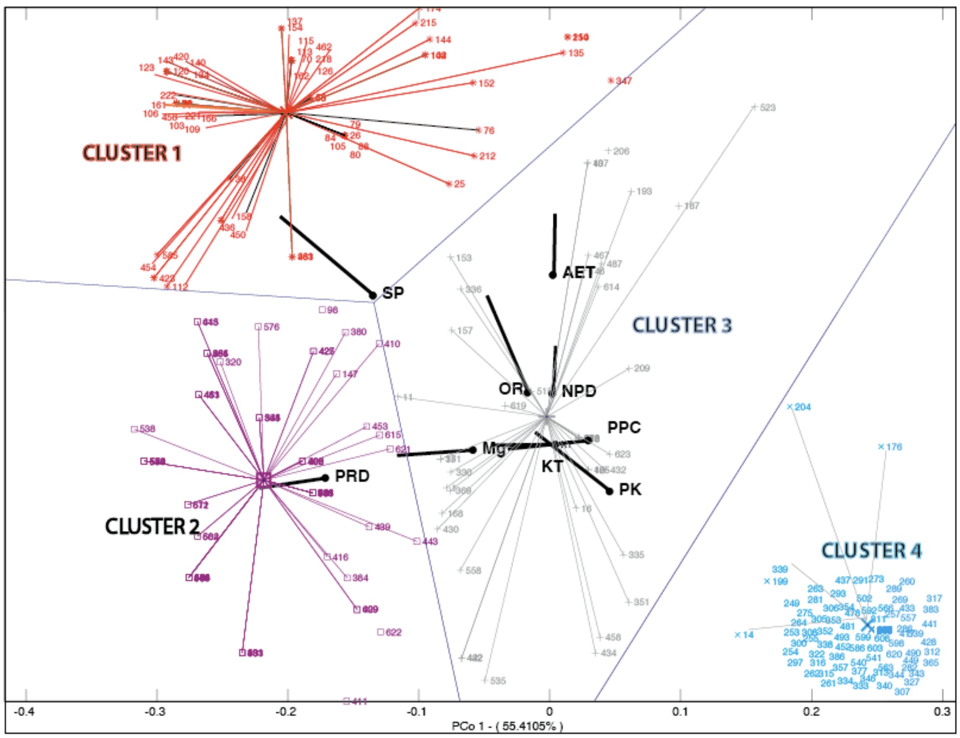

Figure 5: Structure of innovation for Lisboa and Vale do Tejo

The indexes of innovation also show two patterns of association: the first pattern contains the following indexes PK, PPC, KT, Or, Mg and PRD (if one of them is present, it is very probable that the other ones also appear) and the second pattern is composed of the indexes of innovation NPD, AET and SP (if one of them is present, the other ones will be as well).

4.2.2. Norte

The analysis shows four clusters indicating four different innovation patterns. Cluster 4 is, again in this case, composed mostly of those institutions without any innovation, corresponding to 78 institutions (50 per cent of the total number of institutions in this region).

In this case the goodness of the fit is 93.53, and 37 institutions (44%) belong to Cluster 4. Table 5 offers a picture of the three remaining types of innovation clusters in Norte.

The horizontal gradient is highly correlated to the indexes KT, PPC, PRD, Mg and less related to SP and PK variables. The second gradient is highly correlated to NPD, AET, and Or variables, and the SE variable also appears to be related to this second gradient, but this index has no discriminatory power between the different clusters.

The horizontal and vertical gradients have the same structures of variables in the global analysis and in the case of Lisbon – probably because this region is the most representative of innovation in the country

Table 5: Innovation clusters for Norte

Cluster 1: 35 institutions (22%)

Presence of	*Absence of*
Knowledge transfer (KT) 97.14 Promoting partnership and cooperation (PPC) 97.14% New product development (NPD) 97.14% Managing (Mg) 94.29% Promoting knowledge (PK) 92.28% Orientation (Or) 91.42% Application of external technologies (AET) 77.14%	Studying process (SP) 48.57% Promoting R&D (PRD) 40%

Cluster 2: 32 institutions (21%)

Presence of	*Absence of*
Promoting partnership and cooperation (PPC) 100% Promoting knowledge (PK) 93.75% Knowledge transfer (KT) 87.5% Orientation (Or) 84.75% Managing (Mg) 78.12% Promoting R&D (PRD) 40.62%	Studying process (SP) 21.87%

Cluster 3: 11 institutions (7%)

Presence of	*Absence of*
Promoting knowledge (PK) 90.90 % New product development (NPD) 90.90% Orientation (Or) 72.72% Application of external technologies (AET) 63.63% Studying process (SP) 54.54%	Promoting partnership and cooperation (PPC) 27.27% Knowledge transfer (KT) 27.27% Managing (Mg) 27.7%

4.2.3. Centro

The analysis shows again four clusters indicating four different innovation patterns. Cluster 4 is composed mostly of those institutions without any innovation. The remaining three clusters are composed of those institutions that innovate (higher gradient of innovation), but for each cluster the attributes combine differently (see Table 6).

The horizontal gradient is slightly different from the one found in Lisbon. The North region has a high correlation to the indexes PPC, PRD, Mg and PK and is less correlated to KT, SP and OR. The second gradient is highly correlated with NPD, AET and SE indexes. The SE index has no discriminatory capacity in the case of Lisbon, but it does have this in the Centro Region. In this case, the goodness of the fit is 93.53 per cent.

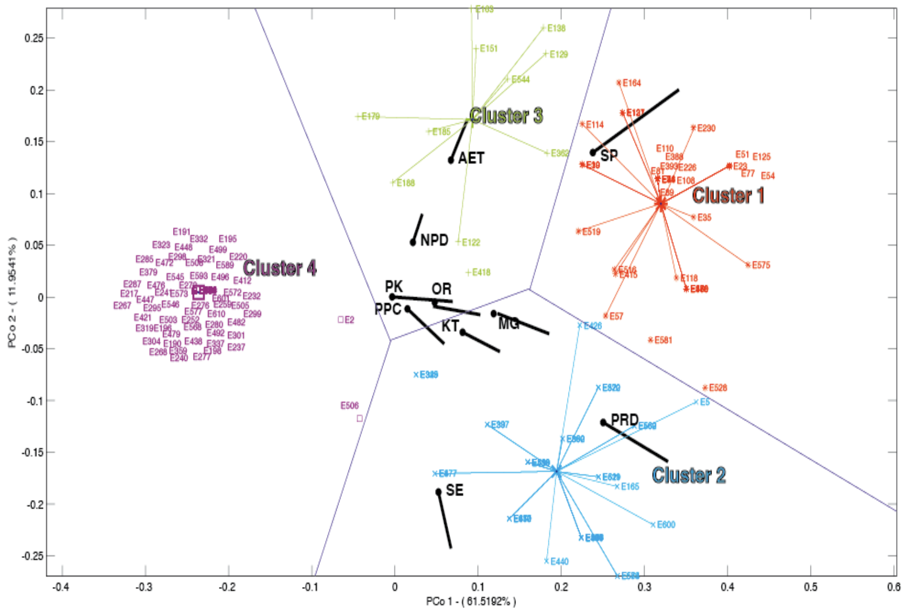

Figure 6: Structure of innovation for Norte

Table 6: Innovation clusters for Cento

Cluster 1: 22 institutions (26%)

Presence of
Promoting partnership and cooperation (PPC) 96%
New product development (NPD) 96%
Promoting knowledge (PK) 92%
Managing (Mg) 88%
Application of external technologies (AET) 84%
Orientation (Or) 80%
Knowledge transfer (KT) 76%

Cluster 2: 13 institutions (16%)

Presence of
Promoting knowledge (PK) 100%
Promoting partnership and cooperation (PPC) 100%
Promoting R&D (PRD) 91.67%
Managing (Mg) 91.67%
Knowledge transfer (KT) 88.33%
Orientation (Or) 75%
Studying process (SP) 66.67%

Cluster 3: 13 institutions (16%)

Presence of
Promoting knowledge (PK) 91.67%
Orientation (Or) 75%
Support to entrepreneurship (SE) 58.33%
Knowledge transfer (KT) 50%

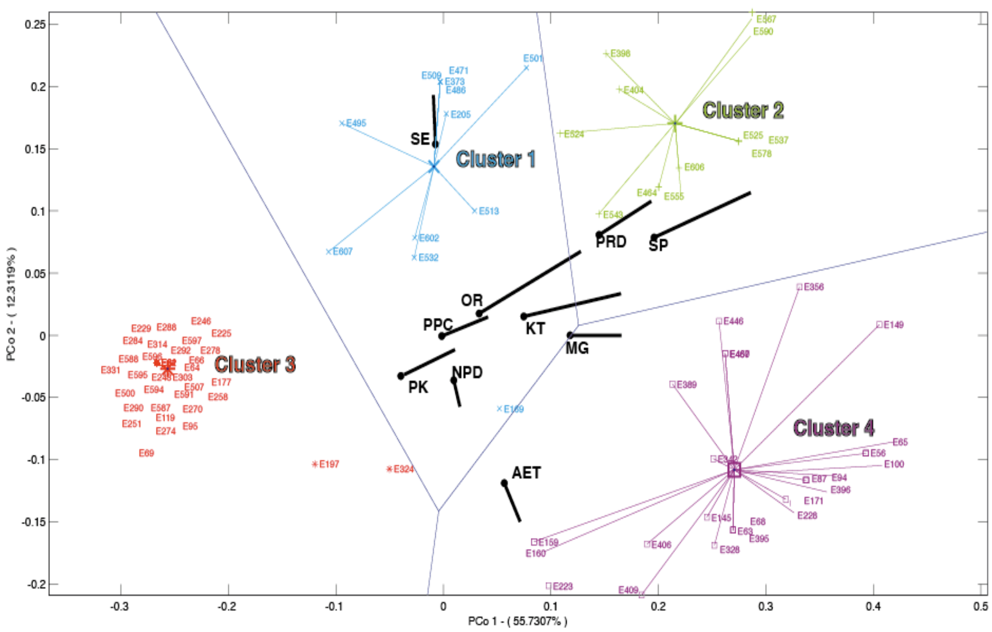

Figure 7: Structure of innovation for Centro

4.2.4. Algarve and Alentejo

The remaining data on these tow regions appeared to be rather rare and incomplete and were not suitable for a further statistical analysis. And therefore, these two regions could not be further investigated.

5. Conclusions

We consider that the major conclusion of the present work is to provide a handy instrument to classify and identify R&D and innovation institutions from an inter-relational, multi-vectorial, and more systemic perspective – a heterodox innovation measure that makes it possible to reproduce the *structure of the innovation* in systems, both at national and regional levels.

From the application of a Logistic Biplot methodology to the institutional databases, it was possible to demonstrate that institutions are very diverse in the way they combine determinants for their patterns of innovation: the two-dimensional PCoA solution accounts for the main interpretation of the variation patterns related to the data set used. The dimensions of the solutions can be interpreted as innovation gradients, which are useful to classify the institutions according to their *degree of complex characteristics leading to innovation.* The sets defined from such complex characteristics are designated by *structures of innovation* – they have been illustrated graphically.

The model was applied at regional level in Portugal, in order to detect the way how the attributes combined per region. *Regional structures of innovation* could in this way be identified. When considering the relation of the variables/attributes to the innovation gradient, we are able to conclude that, for Portugal, in general, the attributes

‘Promoting knowledge’, ‘Managing’, ‘Promoting R&D’, ‘Knowledge transfer’, ‘Promoting partnership & cooperation’ and ‘Orientation’ are the most influential ones.

Thus, the application of the biplot to the Portuguese regional scene confirmed that institutional innovation is influenced by many attributes that are determinants of active functioning, some of which are more important than others. And, by detecting the types of structures underlying the institutions in Portugal, many advantages and fragilities may be identified and clearly interpreted, both from a micro- and a macro-economic view, as suggested in Section 1. For Portuguese policy makers, many lessons can be derived, such as a total geographical asymmetric use of attributes by firms, such as the marked lack of innovative performances in the southern part of the country (the method could not be applied to Algarve and Alentejo because of the lack of statistically significant observations), and, massive concentrations of the most innovative performances in the Lisbon and Porto areas. The reasons to justify such contrasts may be identified at cluster level, by region.

In general terms, for policy makers and planners, close observation of the regional representations may suggest those specific measures required to act directly or indirectly on each described attribute, thus facilitating the design of future *tailor-made policies*.

For managers and other executives, firms can compare their individual performance reproduced in a geometrical location with that of the system average. This is a useful tool to reinforce specific measures and improve the relative positioning, which may be done by seeking a more intensive use of the missing attributes.

Ultimately, our analysis allowed to create a ranking of those institutions that have a higher gradient of capacity to innovate. Although not clearly explained in this paper, such a ranking can be carefully observed as the management profile of each institution – a task not developed in this study. Future investigations may, however, develop this suggestion.

Finally, our method provides a systematic empirical basis for a solid and informed discussion on re*gional cluster-architecture* to help focus policies for regional development.

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