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A Taxonomy of Public Research Bodies: A Systemic Approach[1]

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ABSTRACT *Nowadays the governments of industrialised countries, in the presence of reduced public resources, have to assign clear objectives to public research laboratories to increase the competitiveness of firms. The purpose of this article is to analyse the public research bodies of the National Research Council of Italy in order to pinpoint the main typologies operating in the national system of innovation (NSI). This research shows four main types of research institutes as drivers of NSI. The results can supply useful information to policy makers on the behaviour of these structures and on their strengths and weaknesses.*

Keywords: public research sector; public research laboratory; research evaluation; cluster analysis; principal component analysis; type of research institutes; research policy

Introduction

The sector of public research is made up, according to Senker,[2] of those institutions that deal with civil research and benefit mainly from public financing. These organisations are of public property and their chief purpose is to divulge the results of their researches (in other words, military research is excluded). Etzkowitz and Leydesdorff[3] claim, referring to their own theory of the triple helix, that nowadays universities and public research bodies play a fundamental role in the production of inventions and innovations, necessary to the development of a competitive industrial system in a society based more and more on knowledge.

Studies about these institutions in many industrialised countries, among which Italy, United Kingdom, and Finland,[4] show a growing interest in evaluating performance (i.e. results). The measurement and evaluation of research mirror the interest shown by the government in restructuring this sector and in giving clear objectives to public research labs so that they are managed in an effective and efficient way in light of reduced public resources. This situation has pushed many countries, for instance the United Kingdom[5] and Italy,[6] to increase the size of the structures, reducing the activities in certain scientific fields and at the same

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time expanding them in other fields. Throughout this process of transformation, the State, which plays the role of the principal according to the terminology used in the theory of principal–agent, pursues objectives that are often in conflict with those of research bodies (i.e. agents), especially due to a defective knowledge of the information activities of the latter.[7] Within this scenario, the purpose of this article is to analyse the public research bodies of the National Research Council of Italy in order to pinpoint the main typologies operating in the national system of innovation. Classification is an important activity that facilitates theory development in many academic disciplines. Scholars in the field of economics of science and research management have recognised that classification offers an approach for ordering, understanding and improving the management of the different types and forms of laboratories. The existing classifications of public research institutions tend not to consider the scientific performance and productivity of the research laboratories. The present research proposes a classification of the public research labs based on a systemic approach, which considers the performance of the inputs and outputs within each scientific structure. These taxonomic categories of public research organisations can supply useful information on the behaviour of these structures and on their strengths and weaknesses. This information is necessary to policy makers in order to improve the national system of innovation and to managers in order to organise and direct public research laboratories.

In relation to this, the next section describes the theoretical framework, followed by an explanation of the methodology of the analysis. According to Grigorovici *et al.*[8] to advance information society indices means the need for new data (new variables from the different actors within the society); the need for more analysis (on the micro- and meso-level based on the new variables in combination with existing data); the need for a conceptual framework that defines the relevant indicators and the need to formulate a certain order in the development of these indicators. One such framework has been proposed by Kuipers.[9] The methodology should provide information such as how these measurements and classifications could be used, and how to use the results for research policy. In line with these suggestions, the section findings present the data, their sources and the main results drawn from the analysis of the Italian situation. The concluding remarks include a discussion and some research policy implications.

Public Research Organisations in the National System of Innovation

The elements of innovations (i.e. institutional organisations) operating on the national territory have been analysed using various types of approach starting from the basic approach of the National Systems of Innovation (NSI). Several authors have contributed to the development of this concept (Listz already at the beginning of the twentieth century and, in the last few years, above all Lundvall, Freeman, Nelson, Rosenberg, and Metcalfe), but Lundvall[10] has provided the widest and most clarifying definition of NSI. He was the first to include in it not only organisations directly involved in the innovation process but also all the aspects of institutional structures that influence learning, accumulation of knowledge and the search for all things new.[11]

According to a different theoretical elaboration, the complex network of elements operating within a system of innovation can be interpreted referring to the *triple helix* model,[12] according to which 'the selective constraints of the global

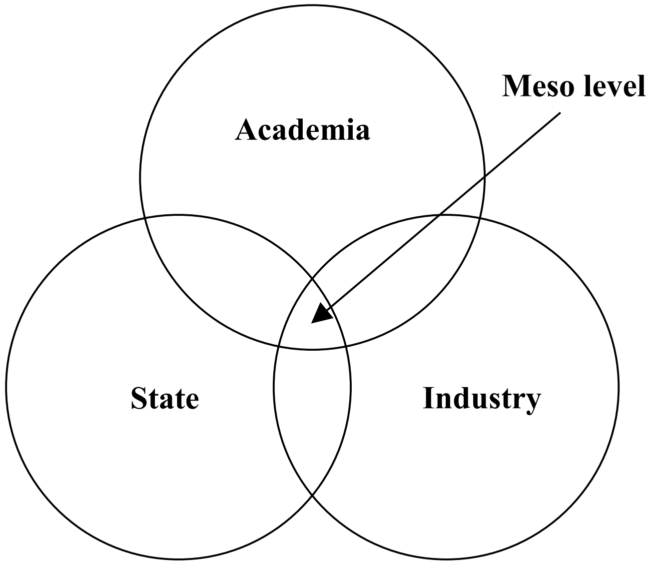

Figure 1. The triple helix model of university–industry–government relations (Etzkowitz and Leydesdorff, *op. cit.*).

market together with the cognitive constraints of the generation of new technological knowledge have brought together three different elements (or institutional spheres): public research labs and academia, industry, and the state, which were in the past much less integrated or simply associated in a binary form' (see Figure 1). In parallel with this first level of elements, which also includes the sources, there is a second or 'meso' level, represented by three main types of institutions (tri-lateral networks and hybrid organisations): *hybrid innovation agents* (directly responsible for the production and use of knowledge), *innovation interfaces* between enterprise and research lab, and *hybrid innovation co-ordinators*, which make up for the faults in spontaneous co-ordination among traditional research organisations.

As mentioned above, public research bodies and universities are one of the main elements of the innovation system and of the triple helix model. Both in Italy and in other industrialised countries they have been widely studied in order to try and improve their efficiency and performance.[13] Around the mid-1980s, the United Kingdom created a commission to carry out a first analysis of the efficiency of university structures. The commission's report, the so-called Jarratt Report,[14] suggested a number of ways to improve the management of scientific-academic organisations. The paths to follow were: (1) an integrated approach to decision making; (2) the development and use of a series of performance indicators, taking inputs and outputs into account, to achieve improved efficiency and to make comparisons among scientific institutions. Another survey, the Morris Report,[15] recommended that polytechnics and colleges develop a set of performance indicators in order to monitor the scientific sector as a whole. Grigorovici *et al.*[16] propose the foundations of the infoMetrics approach for a new framework that may help the e-learning measurement models. Given the recent surge in the development of quantitative measures of e-readiness or e-metrics in both academic and industry research, macro level indicators of information and communication technologies (ICTs) are an essential tool for quantifying the *digital divide*, thus having a profound role in the development of effective policies to overcome it. The problem of developing new indicators is itself an indication of the unique character of the knowledge based economy. In general, improved indicators for the knowledge-based economy are needed for the following tracks:

- measuring knowledge inputs;
- measuring knowledge stocks and flows;
- measuring knowledge networks; and
- measuring knowledge and learning.

It is argued that most existing indicators lack a comprehensive deductive theory to guide them, and that unweighted measures are used too frequently in inter-sector and inter-country comparisons. Gardin[17] has proposed a structure for analysing what statistics and indicators are useful for 'underpinning identification, formulation, monitoring and assessing the new economy'. A model closest to these research objectives is the Information Utilisation Potential (IUP) by Menou.[18] The IUP can provide the theoretical and measurement basis to construct the Information Society index. Menou[19] stated 'the IUP represents the relative present, future, strengths, weaknesses of the countries related to information activities'. This model proves to be the most exhaustive attempt to construct an information index to date. The usefulness of the IUP model lies in the fact that while it uses standardised measures, it is still able and flexible enough to account for variables bundled into final indices. Using the theoretical framework of Gardin[20] and Menou,[21] the approach employed by Grigorovici *et al.*[22] elaborates a theoretical model that is tested iteratively against data to assess its goodness of fit via structural equation modelling.

Public research labs, within the framework of the national system of innovation, are in turn a system that produces goods and services with its own inputs, production processes (related to scientific activities) and outputs.[23]

A system is a set of parts (material and immaterial) that interact and are co-ordinated in order to achieve a common purpose. Research bodies are special systems, managed by humans, which develop a process of scientific production by using resources assigned to them mainly by the State. Beer[24] shows that the n elements belonging to a system display $n(n-1)$ relations achieved by means of the links that join the parts together. Research laboratories, like enterprises, can be considered systems of the *open* type because they have an exchange (of energy, materials, information, etc.) with the surrounding environment (external to the system) and they have feedback, since they are influenced by their past behaviour. Each research body, a very complex structure made up of parts that are mutually dependent on each other and exist in relation with the external environment, can therefore be analysed by means of a *systemic approach*. Considering research bodies as systems means stating that their elements are linked to each other in the execution of scientific research production processes. Scientific research, is an essential raw material for the increase of nations' social well being. Nowadays research laboratories are more and more involved in the economic processes of industrialised countries because they support national enterprises faced with the technological challenges of world-wide scenarios, which have become increasingly turbulent.

When analysing the system of research bodies, the following can be pointed out:

1. *Inputs* are the resources of the system that generate the cognitive process. Within a research lab, inputs are the human factor, information, ideas, equipment, libraries, facilities, and sources of financing.
2. The *production process* of a research body transforms inputs into outputs by carrying out research projects and by organising training courses, service activities, etc. Researchers, thanks to the internal organisation of the research facility, do all this.
3. Research labs' *outputs* are books, manuals, scientific articles, documents, reports, projects, formulas, software programs, innovations of products, processes and organisational features, and patents. These outputs make up explicit knowledge but some studies have shown that within public research bodies there are considerable amounts of tacit activities[25] carried out through internal training and external teaching. Besides these explicit and tacit activities, thanks to the competence gained in specific fields and to the availability of state-of-the-art equipment, research bodies also provide a range of innovative services, such as consultancies, approval tests, crediting, calibrations, certifications, etc. which are a proxy of applied research.
4. The *results* of research bodies are the variables that hold a value for the receiving systems. Public research bodies increase the knowledge of the environment and the level of culture, provide solutions to social problems (economic growth, unemployment reduction ...) and support the increase of competitiveness of the national industrial system (see Figure 2).[26]

When studying research and academic institutions, Harris and Kaine[27] divided researchers into *low, average, and high performers*, on the basis of a series of independent variables represented by preferences and perceptions concerning research activities and their environment.

Within a research project of the *Swiss National Science Foundation*, Balthasar *et al.*[28] studied the professional relation patterns of elements that they called *developers* (people who are involved in technological innovation on a daily basis). They pinpointed four types of institutions involved in training, research and development (R&D), and technological transfer on the basis of different modes of financing. They listed the following types:

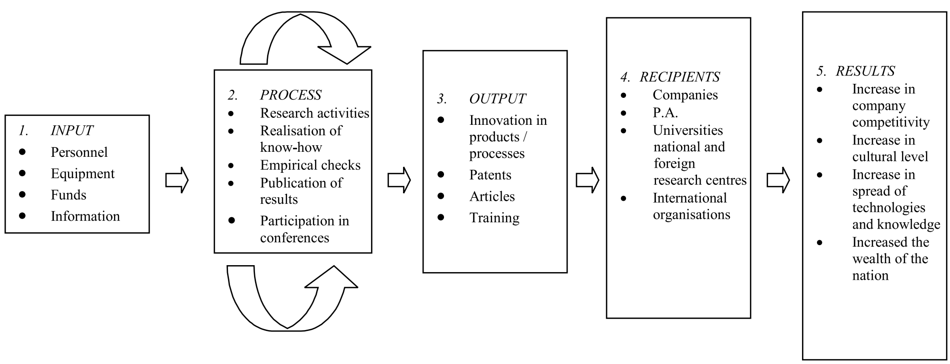

Figure 2. Research laboratories as system (Coccia, 2001a, *op. cit.*).

- The *Science type* relies on considerable research funds independent of industry. This set is financed through basic funding for the benefit of universities as well as from basic and/or applied research programmes. Among its members are university institutions and colleges that carry out not only basic research but also a wide amount of applied research and practical studies.
- *Practical research*: these institutions cover their expenses with funds coming from R&D programmes by the government or from co-operation projects with the industry. They are equipped to satisfy the needs of the market for research and development activities. Their staff includes academics that work on projects in collaboration with industrial representatives. In many cases these institutions are part of universities and they display a considerable growth.
- *Problem solving*: the industry plays a fundamental role in financing this type of institution. Industries provide financial resources by supporting research groups or participation in certain events. In particular, it supports institutes by funding research semesters for professors and provides scientific equipment for training and teaching. These institutions are called upon to investigate simple issues concerning product and process optimisation and they are created by the initiative of the enterprises.
- *Rapid response*: these are mainly financed basic funding to fulfill teaching activities. They do not receive financing for research or technological transfer activities. This category includes professors working in technical universities and/or polytechnics that are called upon to solve small everyday problems, which require an immediate response. These institutions are made up of people with a high degree of technical knowledge and excellent communication skills. They solve problems quickly, in an unbureaucratic manner and they often involve regional industry in scientific research. From this point of view, they carry out indispensable innovative functions.

Besides the above-mentioned types, it is difficult to find other taxonomies in relation to public research bodies and universities. In the university field, for example, Italian faculties are divided into two main categories: science-related (engineering, mathematics, physics and natural sciences, etc.) and humanities-related (economics, law, arts, etc.). As far as public research bodies are concerned, economic literature regarding the types of organisations in relation to their performance and efficiency are scarce. This research attempts to provide a classification of public research institutes, using as its taxonomic criterion a systemic approach based on the inputs and outputs of these structures.

A Systemic Approach as Taxonomic Criterion for Public Research Institutes

Within the field of economics, a problem of definition implies at the same time a difficulty in pinpointing typologies and taxonomies. The identification of these arises from the necessity of indicating homogeneous sets of phenomena. A taxonomic classification is aimed at grouping together and denominating systems on the basis of various types of criteria. The purpose of classification is to provide an orderly layout of systems by using a given criterion. The first systematic taxonomic classification occurred in the field of botany. In his book *Philosophia botanica* of 1751, the Swedish naturalist von Linné developed a binomial nomenclature in order to systematically classify all living organisms. Here a classification of scientific public research institutions is organised on the basis of a systemic approach. The methodology is based on the application of the multivariate analysis, in particular of the analysis of principal components and of clusters in relation to inputs and outputs of the research system. The data examined here is that of the 108 institutes of the National Research Council of Italy (Cnr or CNR), used to draw up the 2003 CNR report.

The variables taken into account for each system-institute are the following, divided into inputs and outputs:

Inputs

1. Cost of personnel
2. Number of research personnel

Outputs

3. Public funds
4. Self-financing
5. Number of personnel in training (trainees)
6. Number of courses held by researchers
7. Number of international publications
8. Number of publications with a national diffusion
9. Number of conferences held at an international level
10. Number of conferences held at a national level

The outputs, in particular nos. 7–10, are proxies to measure both the knowledge stocks, and knowledge outputs. While the variables 5 and 6 are indicators of knowledge diffusion and learning within the economic system, the variables 1 and 2 are measures of knowledge input as above mentioned.

The variables have been standardised in order to make it easier to compare them. The next step has been the analysis of the principal components using the Varimax method and Kaiser normalisation.[29] The analysis has identified the principal components among the aforementioned variables, which are the three factors. The final step has been the cluster analysis of these three factors. The cluster is of a hierarchic type and it applies the Ward method and the squared Euclidean distance.[30] The complexity and abundance of calculations, due to the high number of variables, has been overcome thanks to the application of the SPSS® statistical package,[31] which has provided all the results described and analysed in the following sections. This methodology may be used to assess the public research and to apply research policy to improve the efficiency of the nation system of innovation.

Findings: A New T
axonomy of Public Research Institutes Using a Systemic Approach

The source of this research is the data referring to year 2003 of the National Research Council of Italy (CNR), a body that promotes, co-ordinates and disciplines scientific research in Italy in order to endorse the nation's scientific and technological progress. CNR's institutional scientific activities are carried out by 108 research institutes, bodies that operate permanently and whose purposes are research activities aligned with international and European general research tracks.[32] The Government finances these institutes and, together with other public research bodies, they form the Italian network of the national public research system. CNR's present organisation is divided into five scientific fields, dealt with by the different institutes: (1) basic science with research bodies operating in the fields of mathematics, physics and chemistry; (2) life sciences with laboratories working in the fields of medicine, biology, agriculture and molecular biology; (3) earth and environmental sciences (geology, environment, and habitat); (4) social sciences and humanities, including institutions operating in the fields of history, philosophy, and philology; law and political science; economics, sociology, and statistics; artistic heritage; (5) technological sciences, made up of structures operating in the field of engineering, architecture, technology and information technology.

The study of the principal components has produced a series of outputs whose analysis (Table 1). The most interesting outputs are the three new variables, which are the principal components. Instead of the initial matrix 108×10, a new matrix is now considered: 108×3. Table 1 is important because it displays the *rotated loadings* between each of the three components and the strategic variables.

It can be clearly seen that cost of personnel, research personnel, public financing, publications and international proceedings are strictly related to component 1 (cost of personnel = 0.95; research personnel 0.95; public funds 0.78; international publications 0.70; international presentations 0.65); on the contrary, personnel in training and training courses held by researchers are very much related to component 2 (training = 0.91; teaching courses 0.89); last, the variable national publications with 0.93 is deeply related to component 3.

If the first two principal components are represented geometrically, the strategic position of Italian public research institutes can be analysed (Figure 3). The validity of this analysis, i.e. of the compression from 108×10 to 108×3, is displayed in Table 2, which is one of the outputs of the analysis of the principal components. It shows the percentage of the variance of the initial matrix that can be explained with the estimated matrix. It can be seen that the first component has a percentage of cumulative variance of 39.69 (Table 2, last column); the first two of 62.67; the

Table 1. Rotated component matrix[a]

	Component		
Variable (standardized)	**1**	**2**	**3**
1. Cost of personnel	0.950	0.056	0.113
2. Self-financing	0.545	−0.283	0.400
3. Public funds	0.777	0.200	0.006
4. Trainees	0.177	0.909	−0.024
5. University courses held by researchers	0.025	0.894	0.120
6. Number international proceedings	0.648	0.552	0.233
7. Number national proceedings	0.570	0.265	0.573
8. Number international publications	0.697	0.413	−0.101
9. Number national publications	−0.022	0.064	0.929
10. Research personnel	0.949	0.011	0.134

[a]Extraction method: principal component analysis. Rotation method: Varimax with Kaiser normalization. A rotation converged in five iterations.

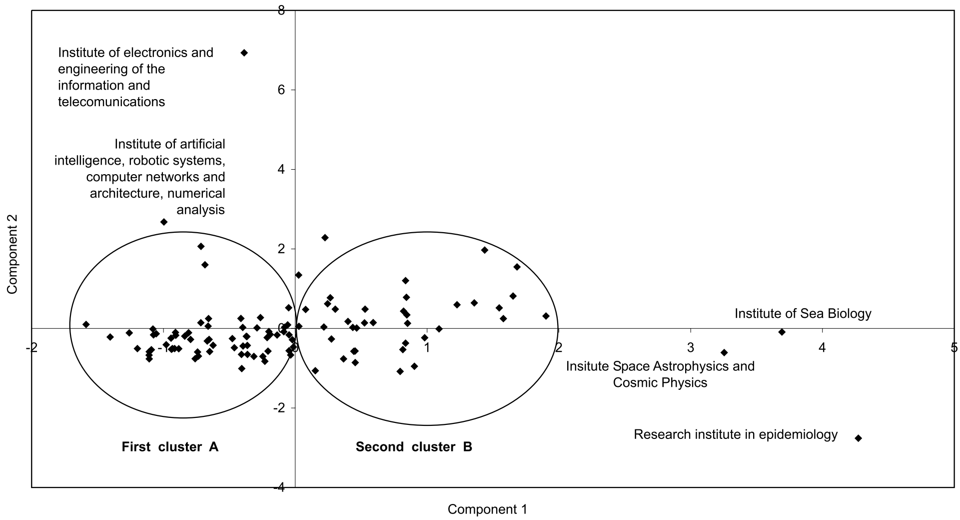

Figure 3. Maps of strategic groups of the research institutes

first three of 77.29. This allows the analysis to be limited to three components since the theory advises against the use of models that explain less than 65% of the variance.

The data of the new 108×3 matrix is used to perform a cluster analysis. The most important output of the clustering process is the dendrogram (Appendix) showing that two clusters can be identified (branches of the main tree). The first corresponds to the A cluster, characterised by institutes with a generally small size and lower performance, while the second cluster B, includes 30 institutes of bigger size and with a higher scientific production dynamism (see Figure 3). Each branch can in turn be divided into further sub-branches. The composition of the various groups is displayed in the following tables that show absolute values (Table 3) and percentage values (Table 4). The Appendix, instead, describes Tables A1 and A2 with the mean and percentage values of the inputs and outputs of each set and subset.

The multivariate analysis described above enables the location of some groups that should not be considered alternative but complementary to each other within the national system of innovation. The taxonomic criteria adopted here and based on inputs and outputs of public research institutions make it possible to single out four main categories of public research labs. These groups have been singled out

Table 2. Total variance explained

	Initial eigenvalues			Extraction sums of squared loadings total			Rotation sums of squared loadings total		
Component	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.710	47.098	47.098	4.710	47.098	47.098	3.969	39.687	39.687
2	1.817	18.168	65.266	1.817	18.168	65.266	2.299	22.987	62.674
3	1.203	12.027	77.293	1.203	12.027	77.293	1.462	14.618	77.293

Table 3. Clusters for research fields

	Basic sciences	Life sciences	Earth and environmental sciences	Social and human sciences	Technological engineering and information sciences	Total
			Cluster: A *Institute: Total number 78*			
Number of institutes (subsets)	**12**	**27**	**7**	**19**	**13**	**78**
A1	1	9	5	14	5	34
A11	1	8	5	14	5	33
A12	0	1	0	0	0	1
A2	11	18	2	5	8	44
A21	8	10	1	1	4	24
A22	1	3	0	4	2	10
A23	2	5	1	0	2	10
			Cluster: B *Institute: Total number 30*			
Number of institutes (subsets)	**16**	**6**	**3**	**0**	**5**	**30**
B1	16	6	3	0	4	29
B11	4	3	1	0	3	11
B12	12	3	2	0	1	18
B2	0	0	0	0	1	1

by means of dichotomic comparisons within each homogeneous cluster category (between A and B, between A1 and A2, between A11 and A12, etc.).

- *LIHO (Low-Input, High-Output or output intensive institute)* are institutions characterised by low public financing and low cost of personnel (input), with a high production of international and national publications and other outputs. These institutions have an excellent internal organisation and use their resources in a highly efficiently manner, thus achieving an outstanding scientific performance.
- *HIHO (High-Input, High-Output or input–output intensive institute)*. These labs have high financial and personnel resources, which result in high outputs and performance.
- *LILO (Low-Input, Low-Output or input–output low intensity institute)*. These labs are complementary to the set above. The limited resources (input) they can avail of (allotment and personnel) are used to produce outputs. The organisation and management structure, as well as the lack of financial resources, does not allow for an increase in their productivity.
- *HILO (High-Input, Low-Output or input intensive institute)*. Contrary to first impressions, these labs are not characterised by organisational inefficiency. The high financial and human resources available are channelled into basic and/or theoretical research activities. These institutes produce outputs in the medium–long term because they carry out fundamental research, which requires long development times to produce outstanding results.

Table 4. Clusters for research fields (%)

	Basic sciences	Life sciences	Earth and environmental sciences	Social and human sciences	Technological engineering and information sciences	Total
			Cluster: A			
			Institute: Total number 78			
% field	**15.38**	**34.62**	**8.97**	**24.36**	**16.67**	**100.00**
A1	2.94	26.47	14.71	41.18	14.71	100.00
A11	3.03	24.24	15.15	42.42	15.15	100.00
A12	0.00	100.00	0.00	0.00	0.00	100.00
A2	25.00	40.91	4.55	11.36	18.18	100.00
A21	33.33	41.67	4.17	4.17	16.67	100.00
A22	10.00	30.00	0.00	40.00	20.00	100.00
A23	20.00	50.00	10.00	0.00	20.00	100.00
			Cluster: B			
			Institute: Total number 30			
% field	**53.33**	**20.00**	**10.00**	**0.00**	**16.67**	**100.00**
B1	55.17	20.69	10.34	0.00	13.79	100.00
B11	36.36	27.27	9.09	0.00	27.27	100.00
B12	66.67	16.67	11.11	0.00	5.56	100.00
B2	0.00	0.00	0.00	0.00	100.00	100.00

The main characteristics of these typologies are now described in detail, trying to point out their structural elements. For clarity's sake, it is first necessary to underline, as said before, that there are two main groups: A and B.

- A has two subsets A1 and A2; in turn, A1 has the two subsets A11 and A12, while A2 has A21, A22, A23 as its subsets; in terms of set theory the following can be written: A1, A2⊆A; A11, {A12} ⊆A1; A21, A22, A23⊆A2.
- B has the following structure: B1, {B2}⊆B; B11, B12⊆B1; {B2} is a singleton set, containing only one element, an institute in this specific situation.

LIHO Institutes (Low-Input, High-Output or Output Intensive Institute)

These institutes are contained in a subset of set B1, represented by set B11, which is made up of 11 institutes. In relation to B12, B11 has lower inputs and higher outputs. 36.36% of this set is made up of institutes operating in the field of basic science (set including the physics and chemistry departments), while another 27.27% of it is made up of institutes operating in the sector of life sciences (medicine, biology, etc.). This typology also includes subset B2, consisting of only one very virtuous CNR institute, which is well known for its high performance: the Institute of Electronics and Engineering of Information and Telecommunication. Within the matrix of strategic groups it is located in the north-west corner. The detailed mean values concerning inputs and outputs are displayed in Tables A1 and A2 in the Appendix.

HIHO Institutes (High-Input, High-Output or Input–Output Intensive)

This type of institute is represented by set B and by some subsets of set A, such as A1 and A12. Set B is included in this category even though it has a lower output indicator in comparison to set A, that of national publications. This typology also includes subset A1, which in comparison to A2 always has higher inputs and outputs. Also a subset of A1, i.e. A12, displays characteristics typical of this type of institute except for the output indicators 'training of postgraduate' and 'training courses by researchers'. An analysis of the composition of group B shows that the institutes included in it belong to the following fields: basic science (53.3%) and life sciences (20%). On the other hand, within A1 subsets the major scientific sectors are those related to economics and the humanities, with values above 40%, and to life sciences, with values of around 27%. Instead, A12 is comprised of only one institute, which has been distinguishing itself for years thanks to its good performance, even though it requires a considerable amount of capital in order to be operational since it is also a hospital: the Institute of Clinical Physiology (or epidemiology). Within the matrix of strategic placement it is located in the south-east corner (Figure 3). It can be seen that A12 is a subset of A1 and, since they both belong to the HIHO (*input–output intensive*) set, it becomes clear that the first set is the bearing structure of the second. Similar remarks can be applied to the other cases.

LILO Institutes (Low-Input, Low-Output or Input–Output Low Intensity)

These laboratories are complementary to the previous group and they are represented by set A as well as its subgroups A11, A2 and A22. These institutes operate prevalently in the sectors of life sciences, social sciences and the humanities, except for field A2, which mainly comprises structures working in the fields of life sciences (44%) and basic science (25%).

HILO Institutes (High-Input, Low-Output or Input Intensive)

This last type can be found within set B1, which is mainly composed of set B12, including 18 institutes operating in the field of life sciences (16.67%) and basic science (66.67%). These institutes carry out almost exclusively basic research activities that require the investment of a high amount of resources, as in the case of the institute of astrophysics, the institute of genetics, the institute of interplanetary space physics, and so on. The institutes operating within this group are basic science based.

Discussion, Concluding Remarks and Research Policy Implications

The present discussion is based on the consideration that public research laboratories are not firms. They have, in fact, a different institutional mission. Within enterprises, the measurement of performance can be easily carried out thanks to the availability of data such as profit and/or turnover in a given period of time (for instance, a single year). Furthermore, in relation to the field of firm, the neoclassical theory states that firms maximise profits,[33] while the behavioural theory[34] shows that the purpose of an enterprise is to keep a satisfactory behaviour (satisficing) by pursuing five objectives: production; stocks; sales; market shares and profit.

The measurement of performance in the sector of research can be difficult due to a variety of reasons: first of all, this is an imperfect market, due to the absence of prices which makes it difficult to measure efficiency. Moreover, the objectives of scientific institutions are more complex then those of firms. A university or a public research body should maximise its prestige, which in turn is a function of other variables that are not easily measured. Many institutes carrying out research activities are public and financed by the government, who may wish to maximise the added value for society. Social efficiency implies a wide spreading of the research results and, once these are spread, the new knowledge becomes a public good,[35] which sometimes leads to a failure of the market. Furthermore, the forces within the market do not operate towards equalising the efficiency of the institutions and this seems to justify the persistence of gaps arisen between various scientific institutions.

The methodology applied here, using a systemic approach based on inputs–outputs, has made it possible to work out a taxonomy of research institutes, which represent the structure of the Italian system of innovation and likewise of the system of innovation in several industrialised countries. The existence of groups of research institutes derives from the fact that several public research organisations have similar structures and management and they carry out similar scientific activities. The presence of HIHO and HILO institutes is linked to the specific basic research activities carried out by such research institutions. In fact, they need a high amount of resources to be able to operate properly since they pursue fundamental researches that will produce substantial results in the medium–long term with considerable effects on the economic system in terms of an increase in social well-being. In the latter case, public financing to research activities is justified by the fact that, besides being a product that enhances society (like, for instance, the discovery of a star, of a new animal species, etc.), scientific production is also an investment that generates effects in terms of scientific-technological progress, increase in the competitiveness of enterprises, improvement of the standard of living and therefore also in terms of a bigger wealth produced by the nation in the medium–long term.[36]

The productivity of public research institutes cannot be considered as a discriminating criterion concerning their higher and/or lower efficiency. The existence of two main types of institutes, HIHO and LILO, within the Italian CNR proves that output productivity also depends on the financial resources invested in research and development, and where there are more resources there is on average also more output. Besides financial resources, Harris and Kaine[37] have assessed that high performance levels are also associated with a strong motivation in undertaking new research activities, with a high degree of interaction with other scientists and with stimulating research environments, which increase *job satisfaction and work involvement*.[38] Furthermore, it must not be forgotten that the matter of allocating resources is strongly influenced by political and scientific lobbies, which causes the resources to be always directed towards those institutes in which the expenditure for research activities already corresponds to a high percentage of the budget, to the disadvantage of scientific structures and/or fields that are not as large. Studies performed by Hare and Wyatt[39] in the UK clearly showed that financing policies were always put into practice to the advantage of strong universities that became more and more powerful to the disadvantage of less strong universities, whose resources and performance were therefore constantly decreasing. The presence of HILO (input intensive) research labs within the national system of innovation is due to the fact that some institutes, because they carry out peculiar types of researches (astronomy, interplanetary space physics, genetics, matter physics, etc.), require conspicuous financing that will produce results only in the long term. Increasing the performance of public research labs is an objective that must always be pursued within the national system of innovation, regardless of the scientific field the institute operates in. Nowadays, this objective has gained a considerable relevance in relation to a rational use of more and more limited public resources. Concerning HILO and LILO institutes, the research policies to increase their efficiency and performance could be based on the application of an incentive-based structure. In the first case, researchers could be moved to those structures that have research scopes, equipment and organisations more suited to their personal inclinations towards research. In the second case, researchers could receive more conspicuous financing in a given year on the basis of the results achieved during the previous year in terms of national and international publications, patents, and so on. The taxonomic system mentioned above has been created in a period when the Italian CNR has undergone a consistent restructuring and this could account for unstable results. Without a doubt, the four taxonomic types described above are always present within the national system of innovation. However, the future developments of this research will aim at providing further empirical evidence in order to asses whether the internal composition of the groups will remain unchanged and/or in which direction inter-group migrations will occur, thus increasing and/or decreasing the number of performance indicators as well as the amount and the size of each group. The aim will also be to try and analyse the underlying causes of such changes and movements.

Notes and References

1. The present work, a continuation of the research which began in 1998, analyses the activities of the public research institutes within the Italian national research council (CNR). While I alone am responsible for any errors or omissions to be found in the text, I wish to thank those who offered a contribution in scientific terms and in personal support, amongst them Professor Secondo Rolfo (Ceris-CNR), for the intense scientific cooperation and Mrs Silvana Zelli of Ceris-CNR for the meticulous computer elaboration of the CNR database. Particular thanks go to Professor Luca Gnan of the Bocconi University in Milan (Italy), for his useful tuition in SPSS software in economic modeling and Professor Donald Lamberton of the Australian National University in Canberra, for useful comments and suggestions. I also am indebted to all the staff of Ceris-CNR for their research assistance.
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29. The principal component analysis (PCA) or *Karhunen–Loeve transform* is a mathematical way of determining that linear transformation of a sample of points in *N*-dimensional space, which exhibits the properties of the sample most clearly along the co-ordinate axes. Along the new axes the sample variances are extremes (maxima and minima), and uncorrelated. The name comes from the *principal axes* of an ellipsoid (e.g. the ellipsoid of inertia), which are just the co-ordinate axes in question. PCA extracts components to maximise the proportion of variability explained by each component, subject to the orthogonality constraint. R. K. Back, *The Data Analysis Briefbook*, Springer, Berlin, 1998. The objectives of the PCA are: (a) to discover or to reduce the dimensionality of the data set; (b) to identify new meaningful underlying variables. By their definition, the principal axes will include those along which the point sample has little or no spread (minima of variance). Hence, an analysis in terms of principal components can show (linear) interdependence in data. A point sample

of N dimensions for whose N co-ordinates M linear relations hold, will show only (N–M) axes along which the spread is non-zero. Using a cut-off on the spread along each axis, a sample may thus be reduced in its dimensionality. (See C. M. Bishop, *Neural Networks for Pattern Recognition*, Oxford University Press, Oxford, 1995.) The principal axes of a point sample are found by choosing the origin at the centre of gravity and forming the dispersion matrix. The principal axes and the variance along each of them are then given by the eigenvectors and associated eigenvalues of the dispersion matrix. Principal component analysis has in practice been used to reduce the dimensionality of problems, and to transform interdependent co-ordinates into significant and independent ones. An example used in several particle physics experiments is that of reducing redundant observations of a particle track in a detector to a low-dimensional subspace whose axes correspond to parameters describing the track. In practice, non-linearities of detectors, frequent changes in detector layout and calibration, and the problem of transforming the co-ordinates along the principal axes into physically meaningful parameters, set limits to the applicability of the method. A simple programme for principal component analysis is described in M. J. O'Connel, 'Search program for significant variables', *Comp. Phys. Comm.*, 8, 1974, p. 49 . Although this is an efficient way of reducing and/or recognising the dimensionality of the data, it may not produce the best projection for interpretation purposes. It may be possible to simplify the interpretation if axes are rotated so that a view of data, the projection, is obtained which is easier to interpret. The problem now becomes one of selecting between all of the possible projections. As the axes are rotated the variable loadings change. One criterion that could be used is to find the 'simplest' combination of loadings. One commonly used method is the Kaiser's Varimax method: (H. F. Kaiser, 'The varimax criterion for analytic rotation in factor analysis', *Psychometrika*, 23, 1985, pp. 187–200) which uses the variance of the loadings to obtain a solution in which each loading is as close as possible to either 0 or 1. Recall that factor loadings are correlation coefficients, thus if a variable has a large (absolute) loading it is highly correlated with a factor, while a small loading indicates no correlation. The aim of the Varimax rotation is to remove, as far as possible, loadings in the mid range, e.g. 0.3–0.7. Ideally, each variable will have a large loading for only one factor.

30. The term *cluster analysis* (first used by Tryon, 1939; R. C. Tryon, *Cluster Analysis*, McGraw Hill, New York) encompasses a number of different algorithms and methods for grouping objects of a similar kind into respective categories. A general question facing researchers in many areas of inquiry is how to *organise* observed data into meaningful structures, that is, to develop taxonomies. In other words, cluster analysis is an exploratory data analysis tool which aims at sorting different objects into groups in a way that the degree of association between two objects is maximal if they belong to the same group and minimal otherwise. Hierarchical cluster analysis is a statistical method for finding relatively homogeneous clusters of cases based on measured characteristics. It starts with each case in a separate cluster and then combines the clusters sequentially, reducing the number of clusters at each step until only one cluster is left. When there are N cases, this involves N–1 clustering steps, or fusions. This hierarchical clustering process can be represented as a tree, or dendrogram, where each step in the clustering process is illustrated by a join of the tree. The joining or tree clustering method uses the dissimilarities (similarities) or distances between objects when forming the clusters. Similarities are a set of rules that serve as criteria for grouping or separating items. These distances (similarities) can be based on a single dimension or multiple dimensions, with each dimension representing a rule or condition for grouping objects. The most straightforward way of computing distances between objects in a multi-dimensional space is to compute Euclidean distances. This is probably the most commonly chosen type of distance. It simply is the geometric distance in the multidimensional space. It is computed as: distance$(x,y) =\{_i(x_i - y_i)^2\}^{1/2}$. You may want to square the standard Euclidean distance in order to place progressively greater weight on objects that are further apart. This distance is computed as: distance$(x,y) = {}_i(x_i - y_i)^2$. Ward's method within the cluster analysis is distinct from all other methods because it uses an analysis of variance approach to evaluate the distances between clusters. In short, this method attempts to minimise the Sum of Squares (SS) of any two (hypothetical) clusters that can be

formed at each step. Refer to J. H. Ward, 'Hierachical grouping to optimize an objective function', *Journal of the American Statistical Association*, 58, 1963, pp. 236–44 for details concerning this method. In general, this method is regarded as very efficient, however, it tends to create clusters of small size.

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Appendix: Tables and dendragram

Cnr report 2003 — **Table A1. Arithmetic Mean**

	No. INSTITUTE	**Cost of personnel 2002**	**Payroll**	**Researches**	**Tech-nicians**	**Adminis-trative**	**Public funds**	**Self-financing**	**Trainees**	**Courses**	**International publications**	**National publications**	**International proceedings**	**National proceedings**
A	78	2670369.95	52.46	30.23	17.51	4.72	375769.51	1220725.35	16.97	8.68	37.94	15.23	44.58	29.37
A1	34	3195312.70	62.26	34.74	21.50	6.03	458055.40	1832948.99	19.47	11.88	38.03	29.91	58.82	45.44
A11	33	2931690.30	56.76	32.52	18.85	5.39	452562.91	664527.80	20.06	12.15	35.39	29.36	55.06	43.12
A12	1	11894852.11	244.00	108.00	109.00	27.00	639307.45	40390848.23	0.00	3.00	125.00	48.00	183.00	122.00
A2	44	2264732.38	44.89	26.75	14.43	3.70	312184.97	747643.44	15.05	6.20	37.86	3.89	33.57	16.95
A21	24	2468338.34	47.79	29.58	14.42	3.79	358050.72	448439.89	22.67	9.04	48.83	3.54	45.08	19.63
A22	10	1369492.05	27.20	14.70	9.60	2.90	199179.79	269260.01	4.60	3.50	11.00	6.60	18.90	15.70
a23	10	2671318.39	55.60	32.00	19.30	4.30	315112.32	1944115.39	7.20	2.10	38.40	2.00	20.60	11.80
B	30	5286485.85	98.07	58.97	30.83	8.27	770884.05	1228244.21	45.13	23.23	103.90	6.30	93.07	39.80
B1	29	5342309.56	99.34	59.34	31.55	8.45	768921.15	1247785.05	37.34	20.14	103.38	6.07	88.97	40.00
B11	11	4881263.73	89.82	57.27	25.55	7.00	645336.60	984235.89	56.82	38.45	108.82	7.91	118.91	59.09
B12	18	5624059.79	105.17	60.61	35.22	9.33	844445.04	1408842.87	25.44	8.94	100.06	4.94	70.67	28.33
B2	1	3667598.13	61.00	48.00	10.00	3.00	827808.12	661559.94	271.00	113.00	119.00	13.00	212.00	34.00

Cnr report 2003		Table A2. % value												
	No. INSTITUTE	**Cost of personnel 2002**	**Payroll**	**Researches**	**Tech-nicians**	**Adminis trative**	**Public funds**	**Self-financing**	**Trainees**	**Courses**	**International publications**	**National publications**	**International proceedings**	**National proceedings**
A	78	33.56	34.85	33.89	36.22	36.33	32.77	49.85	27.33	27.20	26.75	70.74	32.39	42.46
A1	34	58.52	58.11	56.49	59.84	61.94	59.47	71.03	56.41	65.70	50.11	88.50	63.67	72.83
A11	33	19.77	18.87	23.14	14.74	16.65	41.45	1.62	100.00	80.20	22.07	37.96	23.13	26.11
A12	1	80.23	81.13	76.86	85.26	83.35	58.55	98.38	0.00	19.80	77.93	62.04	76.87	73.89
A2	44	41.48	41.89	43.51	40.16	38.06	40.53	28.97	43.59	34.30	49.89	11.50	36.33	27.17
A21	24	37.92	36.60	38.78	33.28	34.50	41.04	16.85	65.76	61.75	49.71	29.17	53.30	41.64
A22	10	21.04	20.83	19.27	22.16	26.38	22.83	10.12	13.35	23.90	11.20	54.36	22.34	33.32
a23	10	41.04	42.58	41.95	44.56	39.12	36.12	73.04	20.89	14.34	39.09	16.47	24.35	25.04
B	30	66.44	65.15	66.11	63.78	63.67	67.23	50.15	72.67	72.80	73.25	29.26	67.61	57.54
B1	29	59.29	61.96	55.28	75.93	73.80	48.16	65.35	12.11	15.13	46.49	31.83	29.56	54.05
B11	11	46.46	46.06	48.58	42.04	42.86	43.32	41.13	69.07	81.13	52.10	61.53	62.72	67.59
B12	18	53.54	53.94	51.42	57.96	57.14	56.68	58.87	30.93	18.87	47.90	38.47	37.28	32.41
B2	1	40.71	38.04	44.72	24.07	26.20	51.84	34.65	87.89	84.87	53.51	68.17	70.44	45.95

Dendrogram using Ward Method