Models for Measuring the Research Performance and management of the public labs

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Abstract. The science sector, in some European countries, is doing a strategic restructuring due to budget cuts (e.g. Italy). Thus, the measure and evaluation of research performance (metrics) of its units (public research institute) is needed. General models to assess the R&D performance of a public research lab are presented here. The methodology uses the discriminant analysis and the results are two canonical discriminant functions (direct and Wilks methods) that could provide indications about the performance of research bodies. The functions are successfully applied to 200 public research institutes belonging to the Italian National Research Council. These functions are also tools for appropriate decisions and actions to improve research performance, especially by the more effective use of existing resources and for reducing the X-inefficiency. Some policy and management implications are discussed.

Keywords: Research performance, Performance measurement, Performance indicators, R&D evaluation, Public research lab, Discriminant analysis, X-inefficiency

Jel Classification: C1, H50, L32, O32

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CONTENTS

Introduction

The debate on the restructuring of the research sector in many European countries has recently become more important, both due to the reduction in public funding, and due to the domination of the United States and Japan in the field of new technology (Senker, 2001). Research is discussed both in terms of the method of public financing, and in terms of production. At the roots of the debate are certain fundamental questions. Which is the most efficient way of producing and spreading research? What should the role of the public and private sectors be in this production process? Is enough being spent on research? Is the money spent, spent well?

Etzkowitz and Leydesdorff (2000) with their theory of the triple helix state that the universities and the public research bodies today play a fundamental role in the production of inventions and innovations, necessary for the development of a competitive industrial system, in a society that is increasingly knowledge-based. The public research sector is formed, according to Senker (2001), by those institutions that deal with civil research and where the majority of the funding is from public sources: these organizations are public property or under the control of public authorities and their principal aim is to spread the results of their research (in other terms military research is excluded). In Italy there is the worry that the research resources are insufficient for strengthening the Italian national system of innovation in terms of production and diffusion of scientific results in the economic system. The studies on these institutions in many countries, including Italy (Coccia and Rolfo, 2002), the United Kingdom (Hariis and Kaine, 1994; Senker, 2001) and Finland (Luwel et al., 1999), show a growing interest in evaluating performance (results). The measuring and evaluation of research performance (metrics) reflect the interest of the Government, which assign clear objectives to the research laboratories so that they can be managed efficiently and efficaciously in the light of the diminishing public resources. This situation has led some countries, for example the United Kingdom and Italy, to increase the size of the labs, eliminating some laboratories and reducing the activities in some scientific fields. In this process of transformation the Government, as principal, using the terminology of the theory of contracts, often has objectives that are in conflict with those of the research bodies (agents), above all due to imperfect knowledge of their activities (Radner, 1987; Hart and Holmstrom, 1985; Levinthal, 1988). The principal (Government), within the research system, could have as objective function the maximization of the added value of the less productive institutions, seeking to level out performances. Identifying the HPI (high performance) and the LPI (low performance) institutes can reach this objective. In this paper the aim is to construct a function for measuring the R&D performance of the public research bodies, in order to facilitate the identification of the most and the least productive laboratories, and to back policy decisions on the level and the direction of the public funding of research.

After this short introduction, the section two will examine the measurement of R&D performance in economic and management literature. Part three will explain in detail the models. Part four will present the results on the institutes of the largest Italian public research bodies, the *Consiglio Nazionale delle Ricerche*, where research is produced and distributed at national and international level. The work concludes with a discussion and some management and policy implications.

1. Research organizations and performance indicators

The principal output of the research system is knowledge (Hare and Wyatt, 1992) which may be presented in various forms: information in articles and books, innovative prototypes, patents, know-how, consultancies or training of personnel. This output is produced by research activities using funds issued by the Government or from the market, which invests in various ways: setting up laboratories, purchasing equipment, books, journal, missions, purchasing consumable materials, offering scholarships and fellowships, etc. Public funding of research can be justified in two ways: the first is the production of a cultural product that educates and entertains the public (the discovery of a star, of a new animal species, etc.). Although this is important, it is not this type of subject used when supporting public research, the policies used by governments is that scientific research is an investment that gives a return in terms of scientific-technological progress, increase in company competitivity, improved standards of living and therefore greater wealth produced by the nation (Metcalfe, 1999).

Whichever orientation is considered, the knowledge is produced by research labs, which nowadays have a pressure of the government for increasing the efficiency. The public research bodies and the universities, are affect, both in Italy, and in the developed countries by a new culture defined as performance oriented (Ball and Wilkinson, 1994). In fact in the mid-nineteen eighties, the United Kingdom set up a commission to analyze the efficiency of the university institutions. The commission's report is known as the Jarratt Report, and it recommended a number of ways of improving the management of the scientific-academic organizations. The methods suggested were: 1) an integrated approach to decision making; 2) the development and use of a series of performance indicators considering the input and the output in order to improve the efficiency and allow comparison between the various scientific institutes (Jarratt, 1985). Another report known as the Morris Report (1990), recommended the universities and colleges to develop a set of performance indicators that would promote the interests of the scientific sector. These indicators, unlike those described in the previous report, referred to scientific fields and not to the institutes or labs. West (1986) applied a series of performance indicators to the strategic planning process at the University of Strathclyde, using the poly-directional matrix within which each department was positioned. The performance indicators for the laboratories were both internal (they fixed the position of the organization on the vertical axis), and external (they fixed the position of the organization on the horizontal axis). The planning committee for this method was so firmly convinced of its efficiency that one of the members voted to close his own department (Ball and Wilkinson, 1994). The DES (Department of Education and Science, 1991) published a report on the use of performance indicators in higher education and the research showed that many institutions that used them improved the organizational management and the attainment of strategic objectives (goals).

The research lab that produces goods and services with its input and production processes (of scientific activity), is function of P = persons, G = goods, O = organization; mathematically it is possible to say:

Output of Research Lab = f (Persons, Goods, Organization)

The research lab is not identified by the sum of the three elements, but is the result of their combination according to certain rules that make up the laws of the organizational system. Many studies on measurement of the performance of the research bodies consider only the bibliometric (Narin and Hamilton, 1996), technometric (patents) or productive indices, which clearly give partial and non-systemic indications of the productivity of the scientific lab. Recent developments have created indicators that measure all the aspects of the activities of the scientific bodies and which are accurately synthesized through particular forms of clustering (Geisler, 2000; Sexton, 1986; Rubenstein and Geisler, 1991). Geisler (1995) began with a series of indices and derived a global indicator with normalized weighting of the elements. The construction of these macro indicators must obey the conditions of orthagonality, in order to avoid multiple counting of the measures in the final indicator. The independence of the measurements that make up the final index is assured by the following three criteria: a) the measurements selected must be the widest number of characteristics; b) the indicators must be limited in order to allow them to be grouped in small sets which represent the phenomenon; c) the sets must contain reciprocally exclusive indices; moreover, in general the weightings of the various elements are generally assigned arbitrarily by the evaluator (Stainer and Nixon, 1997). The macro index obtained following the above criteria is known as the "factor" and gives an approximation of how science generates benefits for the organizations that produce it (sources) and the receiving system. Geisler (2000) says Factor alpha = index of immediate output; Factor beta = index of intermediate output; Factor gamma = index of pre-ultimate output; Factor omega = index of ultimate output. The beta factor, for example, describes how the companies absorb the output of science and transform it within their internal processes, while the omega factor describes the total impact of science on society.

In the cluster of the immediate output, the normalized positive weightings are assigned to every measurement and indicator so that:

$$0 < W_{ia} < 1 \quad a = 1,2,...,n(i) \quad \textit{and} \quad \sum_{a=1}^{n(i)} d_{ia} w_{ia}$$

where i = number of the indicator; $n(i)$ = number of the measurement of the i-th indicator. So that for every indicator the value is the sum of the weighted measurements. These factors are tools for managers and policy makers when evaluating Science and Technology (S&T) at different levels (for example a policy maker will concentrate on the omega factor).

In a previous work Coccia (2001) measured R&D performance on various dimensions, after constructing seven indices that considered all the aspects of the research bodies (financial, technological and scientific), a combination was elaborated, known as *relev (research evaluation labs)* function, which grouped the indices and gave a single output: the R&D performance score. The latter synthesized the financial, technological and scientific aspects of the research organization. The model of evaluation of the performance was called basic model since each operator (index) was given the same weighting in the function. The present work has the purpose to improve the basic model by constructing new models by a canonic discriminating function that assigns differing weights to the various indices in order to obtain a more reliable measuring tool.

Discriminating analysis is applied to a variety of situations by researchers, who often have to classify the cases, characterized by a set of measurements from an unknown source, in various given populations (Kostoris, 1981). In linear discriminating analysis, such as the technique of the principal components the number of characteristics is reduced to reach the maximum separation between the groups given. This method has had various application in research and academic institutions, amongst which the study by Harris and Kaine (1994) which aimed to investigate whether it was possible to predict the position of a researcher in one of the following groups (*low, average and high performers*) on the basis of independent variables represented by preferences and perceptions concerning their research and their environment. In the present research, after identifying two groups of labs represented by those with: a) high performance, b) poor performance; you construct a discriminant function that assigns a research institute to one of the two sets on the basis of a series of independent variables, represented by the funding supplied by the Government, by self-financing, by the number of national and international publications and so on. The method will be described in detail in the next paragraph.

2. Structure and basis of the model

How is it possible to distinguish the institutes with high productivity from those with low productivity? How can the systemic performance of the lab be measured? How can the indicators of scientific productivity be grouped? In this section I will attempt to answer these questions through a modelling activity applied to the public research institutes.

The structure of the methodology is based on the identification of the two complementary sets, characterized respectively by the groups of research institutes with organizational problems and institutes with high performance. In detail the two sets are:

High Performance research Institutes (HPI) - set A

The 30 institutes belonging to set *A*, from various scientific fields, were defined in the document of the Three Year Plan for Italian research prepared by the *Consiglio Nazionale delle Ricerche* (CNR) as organizations that combined scientific excellence and high international visibility. These institutes were leaders in strategic scientific programs for the Italian national research plan. Moreover, other characterizing elements were the multidisciplinary of their activities and the efficacious integrations with universities, professional training schools and the business world. Other research has confirmed their high scientific performance (Coccia, 2001; Coccia, 2001a).

Low Performance research Institutes (LPI) - set B

Set *B* is composed of 30 research institutes, belonging to various scientific fields, that are included in the group due to one or more of the following characteristics: a) they were closed by the Board of the CNR due to the high management costs and low research output; b) they were operating in obsolete fields of research and with personnel close to retiring age, who would have found difficulty in converting to new scientific fields. These factors generated poor performance; c) institutes that for two consecutive years showed low *R&D performance scores* calculated by the relev function (Coccia, 2001). These institutions also had a poor scientific reputation at national level, and the quali-quantitative measurement showed that employees had low job satisfaction (Coccia, 2001a). Finally, these institutions were characterized by a mainly administrative and bureaucratic culture within a world scenario that emphasizes organizational and strategic management skills.

Properties of the sets A and B

1. $A \cap B = \emptyset$
2. $x \in A \setminus B \Leftrightarrow x \in A, x \notin B$.

Once the two sets or groups of the institutions are fixed, I will investigate whether it is possible to predict the location of an institute, taken from a given population, in one of the above sets A or B, on the basis of key variables.

Conceptual model

$$P_i = f(R, TT, F, I)$$

where:

P_i = R&D performance of the research laboratory *i-th*;
R = research activities that generate, for example, national and international publications;
TT = activities of technological transfer (consultancy, patents, etc.);
F = training activities;
I = teaching activities in universities.

Observation 1

The conceptual model will be the basis for measuring the performance of the research.

Hypothesis 1

All the research laboratories generate these activities uniformly in the scientific fields.

Hypothesis 2

The most productive laboratories have a higher R&D performance than the less productive units.

Hypothesis 3

The following five variables that concern the principal output produced in the public research laboratory i-th are considered a proxy of the research performance:

- Self-financing (€) deriving from activities of technological transfer from the institute to outside users
- Training is represented by the number of persons trained within the institute, including stage, thesis, degree students, temporary staff, etc.
- Teaching is the number of courses held by researchers at universities and other high schools
- International Publications are those that appear in journal listed in the Social Science Citation Index
- National Publications are those that have appeared in journal distributed nationally

Hypothesis 4

The high (low) value of the productivity indicators generates high (low) research performance.

Observation 2

From the above variables, the general productivity has been calculated on the basis of the following formula:

$$Productivity = \frac{value\ of\ the\ variables}{Payroll\ personnel}$$

The distribution of the productivity will be analyzed by descriptive statistics calculating the range, the minimum and the maximum value, the sum, the average, the standard deviation and the Kurtosis and Skewness indices. In particular the latter will offer information on the normality of the distributions and where these are not normal, the data will be corrected with the most suitable transformation (the aim is to increase the robustness of the results).

In this research discriminant analysis will be used as a statistical techniques of analysis of cause-effect relationships. In fact, this technique studies the differences existing between two or more groups of cases due to the interactions of a number of variables. The variables will be separated into: a) *groups* that express for each case, the inclusion in a given group; b) *discriminates* which distinguish the cases between the various groups. The basic assumptions of the technique are that the cases must belong to one or more mutually exclusive groups: the discriminant variables must be quantitative and not reciprocally correlated; the matrix of covariance of the various groups must be the same; the groups of cases belong to a normally distributed population.

On the basis of the above assumptions the discriminant function to be calculated takes the following form:

$$S_{rn} = b_{r0} + b_{r1}X_{1n} + b_{r2}X_{2n} + ... + b_{rq}X_{qn}$$

r = number of groups

S_{rn} = score of the r-th discriminant function for the case n

X_{in} = value of the i-th discriminating variable for the case n

b_{ri} = coefficient of the i-th discriminant variable in the r-th discriminant function

Observation 3

Considering the normal operation of the public research laboratory it would be expected that all the signs of the coefficient of the equation S_{rn} should be positive (+).

The complexity of the elaboration due to the high number of variables, both dependent and independent, was overcome by applying the statistical package SPSS® from which all the results described and analyzed in the following sections are drawn. The appendix A shows the main steps of the discriminant analysis.

3. Models for measuring the R&D performance

The model for measuring the R&D performance was constructed using data from the Italian National Research Council (CNR), the body that promotes, co-ordinates and disciplines scientific research in Italy in order to increase the scientific and technological progress of the country. The institutional scientific activity is carried out by 200 research institutes, which have the general aims of research in relation to the programmatic objectives of the CNR and than of the Italian national system of innovation. The organization of the CNR is organized in five scientific fields: 1) Basic science with research bodies in the fields of math, physics and chemistry; 2) Life sciences with labs in the fields of medicine and biology, agriculture and molecular biology; 3) Earth sciences and environment (geology, environment and habitat); 4) Social and human sciences which include the fields of history, philosophy and philology; legal and political sciences, economics, sociology and statistics, historical heritage; 5) Finally there is the field of technological sciences, engineering and information technology formed of labs operating in the fields of engineering, technology and computer science.

The data analyzed is from 2001 period. The descriptive statistics of the variables and productivity within of the HPI and LPI are showed in tables B.1 and B.2 (see appendix B). The variables (indicated in table B.1), before becoming discriminant were transformed into indicators of productivity (dividing their absolute value by the number of research personnel employed in the laboratory) and since they do not respect one of the basic assumptions of the discriminating analysis (normal distribution) the values were transformed into a logarithmic scale in order to have a distribution that tends towards Gauss distribution. The descriptive statistics of the discriminant variables used to distinguish the cases between the various groups are shown in the appendix B - table B.3.

Another variable used in the model is a dummy variables which assumes only two of the values, that is X_j = 1 (for HPI = High Performance Institute, grouped in the set A), X_j = 0 or LPI = Low Performance. This variable expresses for each case its inclusion in-groups or sets A or B. Discriminant analysis was applied both with the direct method (all the discriminant variables), and with the stepwise technique, which uses as a selection method to minimize of the Wilks lambda; in such cases the maximum number of steps is 10, the minimum level of tolerance is 0.001, the minimum level of F to input is 3.84 and the maximum level of F to remove is 2.71. The last method has chosen as discriminant variables the Log_{10} Productivity of Training (entered after the first step), Log_{10} Self-financing Productivity (included in the analysis at the second step) and Log_{10} Productivity teaching (included in the analysis at the third step). Both the models have a prior probability for each group equal to 0.5%, and they have used in the analysis 32 (13 of the HPI set and 19 of the LPI set) of the 60 cases registered on the computer. The mean (centroids) and standard deviation of the discriminant variables for the two subsets of institutes A and B are showed in table B.4, appendix B.

The canonic correlation of each discriminant function (function-group link) are high and equal to R^2_{c1}=0.8311 in the case of the Wilks method and R^2_{c2}=0.8346 in the case of all the variables. These values give the effective discriminant power of the two functions (table 1).

Table 1 – Canonical discriminat functions

Functions	*Eigenvalue*	$\frac{\lambda 1}{\lambda j}$	*Canonical Correlation*	*Wilks' Lambda*	*Chi-square*	*df*	*Sig.*
1. Stepwise Method of Wilks	2.23	100	0.831	0.309	33.44	3	0.00
2. Direct Method (all variables)	2.29	100	0.834	0.303	32.79	5	0.00

The discriminant power of the two functions is confirmed by the Bartlett test which in the case of the first function is b_{c1}=33.44. The theoretical Chi-squared value by 3 degrees of freedom and at the level of probability of 1‰ is16.266. Therefore it is necessary to reject the nil hypothesis (absence of discriminant power). *Coeteris paribus* in the case of the direct method b_{c1}=32.79, with 5 degrees of freedom and 1‰, the χ^2 is 20.515. In both tests the significance is 1‰.

Table 2 shows the discriminant variables classified according to the dimensions of the correlation of the functions. The variables with a correlation above 65% are Log_{10} Training Productivity and Log_{10} Self-funding Productivity. Tables 3 and 4 show the non-standardized and standardized coefficients of the canonic discriminating functions with the group means.

The test of equality of group covariance matrices using Box's M is shown in table 5. Finally, table 6 shows the synthesis of the results, where in both methods the percentage of cases correctly classified is equal to 86.67%.

Table 2 – Pooled within-groups correlation between discriminating variables and canonical discriminant functions

Discriminant variables	*Variables ordered by size of correlation within function*	
$Log_{10}\ Productivity = \frac{Values}{Payroll\ personnel}$	*Function 1* Stepwise Method of Wilks	*Function 2* Direct Method (all variables)
Training	0.671	0.662
Self-financing (€)	0.667	0.658
National Publications	0.449	0.466
Teaching	0.330	0.435
International publications	0.285	0.326

Table 3 – Standardised and unstandardized canonical discriminant function coefficients

	Function 1 Stepwise Method of Wilks		*Function 2* Direct Method (all variables)	
$Log_{10}\ Productivity = \frac{Values}{Payroll\ personnel}$	*Standardized*	*Unstandardized*	*Standardized*	*Unstandardized*
Self-financing (€)	0.696	1.436	0.674	1.389
Training (n. of persons)	0.562	1.521	0.498	1.347
Teaching (n. of courses)	0.478	1.029	0.467	1.007
International Publications (number)			0.176	0.483
National Publications (number)			–0.003	–0.00871
(Constant)		–5.151		–5.178

Table 4 – Canonical discriminant functions evaluated at group means (group centroids)

	Function 1 Stepwise Method of Wilks	*Function 2* Direct Method (all variables)
1. Set A	1.749	1.773
2. Set B	−1.197	−1.213

Table 5 – Test of equality of group covariance matrices using Box's M

	Box' s M	*Approximate F*	*df*		*Significance*
1. Stepwise Method of Wilks	13.815	2.036	6.0	4469.5	0.0574
2. Direct Method (all variables)	43.881	2.359	15.0	2651.5	0.0023

Table 6 – Classification results

Stepwise Method of Wilks			*% Predicted Group Membership*	
Direct Method (all variables)	*Group*	*No. of cases*	*A*	*B*
Set A (HPI Labs)	A	30	25 (83.3%)	5 (16.7%)
Set B (LPI Labs)	B	30	3 (10%)	27 (90%)
	Percent of "grouped" cases correctly classified: 86.67%			

The discriminant functions (direct method and Wilks) applied on 200 CNR research institutes, 2001 period, it showed that little more than 20% of the institutes fall into the set of the HPI (table 7). Moreover, the laboratories classified in this set are those with a medium size (neither too large, nor too small) with respect to the existing research institutes.

Table 7 – Discriminant analysis applied on Italian research labs (results) – data from 2001

	Stepwise Method of Wilks		*Direct Method (all variables)*	
	Set HPI	*Set LPI*	*Set HPI*	*Set LPI*
No. labs 200	45	155	43	157
Means				
❑ Government funds (€)	330,553.85	219,632.86	305,522.99	228,392.73
❑ Personnel cost (€)	1,472,514.54	1,038,573.99	1,301,668.57	1,107,718.81
❑ No. personnel	26	21	23	22
❑ Self-financing (€)	789.41	254.07	789.20	284.95
❑ Training (no. of persons)	18	8	16	9
❑ Teaching (no. of courses)	10	5	10	5
❑ International Publications (number)	67	40	72	40
❑ National Publications (number)	40	20	39	21

4. Discussion and implications for policy and management of research

The public research laboratories are not private firms, but have a different institutional mission and operate in different situations. In private firms the measurement of performance is easy, thanks to measurements such as profit and/or turnover in a given period of time (for example one year). Moreover, in the private field the neoclassic theory has taught us that firms maximize profits (Varian, 1990), while behavioral theory (Cyert and March, 1963) shows that the aim of the companies is to maintain satisfying behavior, pursuing five objectives: production, stocks, sales, market share and profit.

The measurement of the performance in the research sector may be difficult for a number of reasons: first of all we are dealing with an imperfect market, above all due to the absence of prices which make measurement of efficiency more difficult. Moreover, in scientific institutions the aims are more complex than those to be found in private businesses. A university or a public research body must maximize the prestige that in turn is the function of other variables, which are not easily measured. Many institutions that carry out research are public and financed by the government, which intends to maximize the added value for the country. The social efficiency requires extensive diffusion of the results of the research and once distributed, the new knowledge becomes a public good (Arrow, 1962) and this can lead to the failure of the market. What is more, the market forces do not operate to equal the efficiency of the various labs and this seems to justify the existence of a gap between the various scientific institutions.

The models constructed are an improvement of the *relev function* (see Coccia, 2001) and they are called *Relev functions II version*. These functions are:

$M_1 = -5.151 + 1.436X_1 + 1.521X_2 + 1.029X_3$ (Wilks method)

$M_2 = -5.178 + 1.389X_1 + 1.347X_2 + 1.007X_3 + 0.483 X_4 - 0.00871X_5$ (direct method)

where:

X_1 = Self-financing (€)
X_2 = Training (n. of persons)
X_3 = Teaching (n. of courses)
X_4 = International publications (number)
X_5 = National publications (number)

Their application on 200 Italian CNR institutes showed that 22.5% of public research laboratories belong to the HPI group and the size is larger than LPI set. This leads us to a series of important considerations. Moreover the recent reorganization of the Italian science sector which is also dealing with the question of size "by encouraging labs of excellence, merging, transformations and suppressions". The process of reform foresees that the present 200 organizational units will become 108 new institutions. The debate in favor of the existence of a scale in scientific production is due to a series of factors (Johnston, 1993; 1995) such as a critical threshold under which the researchers are not able to activate significant collaborations; moreover, the administrative activity shows costs with a constant increase with respect to the volume of scientific activity, and therefore the smaller bodies have higher management costs (Bonaccorsi, 2001); finally, the larger organizations can invest more resources in risky projects. The conclusion of the studies on the performance of research teams show that some support an increase, others a reduction, and yet others a combination of the two (Hare and Wyatt, 1988). Hicks and Skea (1989) analyze the relationship between size and output, and suggest that although the larger departments are more productive, this dependence is extremely weak and can be easily explained by characteristics not linked to size. At present the CNR has 200 institutes of which 32 have average funding of more than € 413,000, and 51 employees (mean), and more than 90 with an average funding of € 181,000 and 11 employees (average). The results of the discriminating analysis show how HPI are neither the large nor the small, they are of average size represented by € 300-330,000 in funds, with 23-26 employees. The model of discriminant analysis used in this research for evaluating the performance of public research laboratories are similar to those used by Altman (1978) for evaluating private companies, using a series of indices based on the productivity of the various outputs of the firms. The problem that can be raised is whether the performance indicators and the statistical-mathematical analysis alone can be sufficient for evaluating the performance of the public research bodies and the state of health of the organization. The Morris Report (1990) stated that *peer review*, though subjective, offered opportunities for greater analysis of the institutions with respect to the indicators of performance taken individually. These two tools, in my opinion, should complementary. In the absence of indicators of performance, the elements of judgment could be too great, while trusting only one of the indices and technical statistics could be dangerous. The performance indicators (Page, 1989) are good management tools for R&D labs, but they have the weak point that they do not support the scientific and technological policy of a country and, the latter, in the field of research is of fundamental importance. This can be done only with specific action on research policy which introduced greater incentives (Graves et al., 1982), for example awards for the researchers for articles published in international journals, high percentages of profits generated by patents for CNR inventors-researchers (similar to the liaison office in certain US universities), the employment of young researchers, the increase in salary for researchers according to total productivity of the research institutes, certain career paths and promotions linked to the number of scientific recognition attained, and so on. In the presence of high motivation and stimulating environments, Harris and Kaine (1994) have shown that researchers, even after they have reached the peak of their careers, continue to publish and are considered high performers.

If we compare the output of the HPI institutes with that of the LPI in the present work we can see that the former possess a level of scientific production in terms of personnel in training, teaching courses held by the researchers, number of national and international publications more than 50% higher than that of the LPI (set B). Moreover the inclusion in set A or B must not be seen as permanent, since in the field of research the output of the departments that publish very little is only slightly lower than that of the departments that publish more and are therefore HPI (Jones, 1992). A scientific policy of leveling between the various research labs could be, apart from the concentration measures already undertaken, the re-location of personnel in order to allow them to choose in which lab to work, according to their scientific and personal preferences. Harris and Kaine (1994) have shown that levels of high performance are associated with strong motivation for undertaking research, a high degree of interaction with other scientists and a stimulating environment which all increases job satisfaction (Coccia, 2001). The LPIs on the other hand are characterized by poor performance, both due to environmental causes (reduction in funding, changes in the technological trajectories) and due to organizational problems such as internal conflicts in the choice of management, which associated with other problems increases the so-called “X inefficiency” (Leibenstein, 1966). The institutes with poor performance are also characterized by poor interaction between the researchers, who are unlikely to cooperate with others inside or outside the unit. It must also be noted that the allocation of resources is strongly influenced by political and scientific lobbies, since the resources are always directed to organizational units, which have high research budget. Studies carried out by Hare and Wyatt (1992) show that the funding policies greatly effect the stronger universities, which are always preferred over the weaker, who continue to see their resources dwindle.

All in all, the figure 1 shows, as in Italy, there is an inversion of the trend of the principle resources of the research. A series of exogenous causes such as the constant reduction (as of the mid-nineties) of the public funding assigned to the research institutes, the waves of restructuring announced and still to be completed and the introduction of the first system of research evaluation have led to an endogenous change in the research laboratories represented by a different approach from CNR researchers to the market, seen as an important source of the financial resources necessary for carrying out scientific research, which will cause a considerable increase in self-funding. This positive trend, may have negative aspects (figure 2) as already observed by Hare and Wyatt (1992) in the United Kingdom, where at the end of the seventies a cut in the resources for research caused considerable changes in the research and academic institutes, moving them towards activities capable of capturing funds from the market; this transformed the research institutes into organizations focused on consultancy and applied research, with negative repercussions on basic research and therefore on the long-run development of the country. Another danger from the latter tendency is to discourage many young people from undertaking a career in research, with incalculable harm for the internal generation of scientific knowledge (and damage to the occupational structure), and strong dependence on foreign countries for the purchase (where this is possible, at high cost) of technical know-how and innovation, strategic tool for increasing the industrial competitively and economic development. The hope is that the policy makers will not consider self-financing of research a substitute good of the public financing, since this would – over the next decade – produce irreversible damage to the national innovation systems, apart from the already known failure of the market for research (Arrow, 1962).

Figure 1 – Resources dynamic (market funds-government funds) and strategic behaviour of research labs

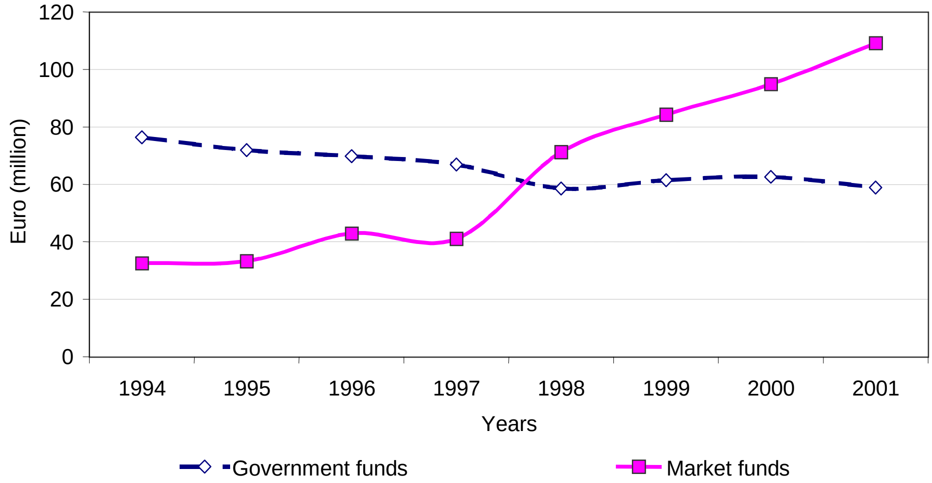

Figure 2 – Strategic behavior of the research institutes and Matrix SWOT (Strengths, Weaknesses, Opportunities, Threats)

Strengths	*Weaknesses*
❑ Increase in self-financing ❑ Savings on public financing ❑ More applied research	❑ Reduction of resources in basic research ❑ Focus on consultancy activities
Opportunities	*Threats*
❑ Support for the competitivity of the company ❑ Growth in the short-run	❑ Reduction in resources invested in scientific and technological progress ❑ Reduction of the development in the long run ❑ Increase of the technological gap from advanced countries ❑ Weak Porter's factor which lead to the countries advantages

Appendix A: Discriminant analysis

Given q variables measured on n distinct units in r groups the following relationship exists:

$$T = W + A$$

Where T is the symmetric matrix q×q of the total variances and codeviances, W is the symmetric matrix q×q of the covariance in the groups and A is the symmetric matrix q×q of the covariance between the groups. The parameters of the discriminant functions are the elements of the eigenvectors of the matrix $W^{-1}A$. The maximum number of discriminant functions that can be identified is equal to the smallest of the two numbers (r–1) and q so that g = min[(r–1), q].

Validation of the model

The characteristic roots of $W^{-1}A$ are λ_h.

The ratio is:

$$\frac{\lambda_h}{\sum_{h=1}^{g} \lambda_h} \in [0,1]$$

gives an index that measures the discriminant power of the h-th function. Moreover the canonic correlation relative to the functions is:

$$R_{ch} = \sqrt{\frac{\lambda_h}{(1+\lambda_h)}}$$

this value explains the effective discriminant power.

Another way of testing whether the functions have discriminant power is to use Bartlett's test:

$$b_c = -(n - \frac{q+r}{2} - 1) \ln \Lambda_p$$

which has a distribution of χ^2 with (q–p)(r–p–1) degrees of freedom (df) and, where the index Λ of Wilks (measures the residual discriminant capacity before the introduction of each function) can be determined in one of the following ways (except for some small differences due to errors of approximation in the calculation of $W^{-1}A$ and its latent roots):

$$\Lambda_p = \pi_{j=p+1}^{g} \frac{1}{(1+\lambda_j)} \qquad \Lambda = \frac{|W|}{|T|}$$

If b_c is greater than the value that is to be found in the distribution χ^2 with (q–p)(r–p–1) degrees of freedom (df) and at fixed level of probability, it will be necessary to reject the hypothesis that the discriminant power of the remaining g-p functions is nil and proceed with the determination of the p+1(th) discriminating function (Sadocchi, 1980).

The relation between the discriminant variables and the functions of canonic discrimination will be found by presenting the first ordinates on the basis of the intensity of the correlation within the function. The test of equality of the matrixes of covariance between the groups will be carried out using Box's M test.

Appendix B: Tables

Table B.1 – Descriptive statistics of the variables

	N. cases	*Range*	*Min*	*Max*	*Sum*	*Mean*	*Std.*
High performance labs (HPI) (set A)							
Self-financing (€)	30	5,681.03	16.94	5,681.03	26,855.76	986.53	1,208.23
Training (n. of persons)		61.00	1.00	62.00	452.00	18.08	15.53
Teaching (n. of courses)		31.00	1.00	32.00	153.00	9.56	9.10
International Publications (number)		277.00	1.00	278.00	2,003.00	69.07	60.69
National Publications (number)		138.00	1.00	139.00	922.00	31.79	30.55
Low performance labs (LPI) (set B)							
Self-financing (€)	30	668.68	9.28	677.96	4,179.81	149.28	145.48
Training (n. of persons)		21.00	1.00	22.00	187.00	6.68	6.16
Teaching (n. of courses)		10.00	1.00	11.00	72.00	3.79	2.64
International Publications (number)		136.00	1.00	137.00	1,107.00	36.90	33.71
National Publications (number)		43.00	1.00	44.00	578.00	19.27	11.97

Table B.2 – Descriptive statistics of the productivity

$\Pr oductivity = \frac{Values}{Payroll\ \ personnel}$	*N. cases*	*Range*	*Min*	*Max*	*Sum*	*Mean*	*Std.*
High performance labs (HPI) (set A)							
Self-financing (€)	30	446.50	0.00	446.50	1,857.27	61.91	89.04
Training (n. of persons)		9.00	0.00	9.00	43.10	1.44	2.10
Teaching (n. of courses)		32.00	0.00	32.00	53.56	1.79	5.85
International Publications (number)		27.00	0.00	27.00	179.20	5.97	7.19
National Publications (number)		19.50	0.00	19.50	93.35	3.11	4.66
Low performance labs (LPI) (set B)							
Self-financing (€)	30	39.88	0.00	39.88	196.55	6.55	7.81
Training (n. of persons)		1.00	0.00	1.00	8.97	0.30	0.25
Teaching (n. of courses)		0.79	0.00	0.79	6.53	0.22	0.26
International Publications (number)		3.92	0.11	4.03	46.60	1.55	0.96
National Publications (number)		2.02	0.11	2.13	29.14	0.97	0.53

Table B.3 – Descriptive statistics of the discriminant variables

$Log_{10} \Pr oductivity = \frac{Values}{Payroll\ \ personnel}$	*N. cases*	*Range*	*Min*	*Max*	*Sum*	*Mean*	*Std.*
High performance labs (HPI) (set A)							
Self-financing (€)	30	2.07	3.86	5.94	130.91	4.85	0.52
Training (n. of persons)		2.35	-1.40	0.95	-1.64	-0.07	0.55
Teaching (n. of courses)		2.66	-1.15	1.51	-0.56	-0.04	0.69
International Publications (number)		2.83	-1.40	1.43	15.28	0.53	0.56
National Publications (number)		2.21	-0.92	1.29	4.73	0.16	0.55
Low performance labs (LPI) (set B)							
Self-financing (€)	30	1.84	3.05	4.89	110.12	3.93	0.44
Training (n. of persons)		1.40	-1.40	0.00	-17.97	-0.64	0.40
Teaching (n. of courses)		1.30	-1.40	-0.10	-11.61	-0.61	0.40
International Publications (number)		1.56	-0.96	0.61	2.24	0.08	0.38
National Publications (number)		1.29	-0.96	0.33	-2.75	-0.09	0.30

Table B.4 – Mean and Standard deviation of discriminant variable split in sets A e B

Diecriminant variables	*Mean*			*Standard deviation*		
$Log_{10} \Pr oductivity = \frac{Values}{Payroll\ \ personnel}$	*HPI (set A)*	*LPI (set B)*	*Total*	*HPI (set A)*	*LPI (set B)*	*Total*
Self-financing (€)	4.85	3.90	4.29	0.62	0.38	0.67
Training (n. of persons)	0.06	-0.67	-0.37	0.33	0.40	0.51
Teaching (n. of courses)	-0.16	-0.61	-0.43	0.54	0.40	0.51
International Publications (number)	0.61	0.13	0.33	0.38	0.37	0.43
National Publications (number)	0.44	-0.12	0.11	0.53	0.27	0.48

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