A Mathematical Model for Performance Evaluation in the R&D Laboratories: Theory and Application in Italy

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Abstract

Aim of this paper is to build a method of performance evaluation for research organization, using a systemic approach that considers the interrelations among activities (administrative, scientific, technologic). The method is based on the **re**search **l**aboratories **ev**aluation (*relev)* function which is a linear combination of seven indices, two financials, two tacit technological transfer, two bibliometrics and one technological. The relev function summarises quantitative, qualitative and cost aspects, it is simple and emphasizes evaluation of R&D outcomes rather than behaviour. The validity of the relev methodology was tested on the National Research Council Institutes operating in North West Italy.

Jel Classification: B41, C20, C43, C60

Keywords: Evaluation, Indices, Performance, Research

Contents

Performance
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over an interval of time in carrying out activities.

1. Introduction

The public and private research bodies are organisations which carry out scientific research (research projects, know-how, etc.), offer services (consultancies, calibration, homologation, certification, etc.) and administrative operations. Nowadays they are increasingly important players within the economic process of the industrialised countries since they support the firms in facing the technological challenges presented by ever more turbulent world scenarios. The need to increase the efficiency and efficacy of these organisations places the elaboration of methodologies for measuring productivity in R & D very much to the forefront (Bozeman and Melkers, 1993; Georghiou, 1998; Sirilli, 1985).

Existing literature on the evaluation of the research laboratories is based above all on the bibliometric and technometric analysis. The bibliometric and technometric indicators do not consider the financial resources available though have an important role to play in the activities of scientific production, since the personnel employed in the research activities depends directly on them. Moreover an evaluation must consider the tacit activity which can be compared to the submerged part of an iceberg, it is not visible, but it is very substantial (Polyani, 1966). In this work it is assumed that the research bodies or laboratories are a system which works within a macro system represented by a large organisation, for example the laboratories of public research organizations are an R & D cell which is part of a larger system that hands down the directives on the basic research with a medium-long term time frame.

A system is a set made up of elements (material and non-material) interacting and co-ordinated in order to reach a common goal (Forrester, 1997). The research bodies are particular systems, set up and run by man, which develop a process of scientific production mainly using resources assigned by the State or firm. The research laboratories, like the manufacturing companies, can be considered *open* systems, since they have interchanges (of energy, materials, information, etc.) with the environment (outside the system), and *feedback*, since they are influenced by their past behaviour. Within all these units it is possible to realise processes (spatial-temporal sequences of events), each of which is connected with the progress and the history of precedents and it is therefore possible, within a given interval of time, to distinguish an initial and a final state of the process. To consider the research bodies *systems* is to state that their elements are connected to each other in carrying out the process of scientific production which generates as an output, the raw research material which is essential for increasing the wealth of the nations. Stafford Beer (1973) shows how the *n* elements of a system present *n(n-1)* relations evidenced by the links which unite the parts. If we consider the research bodies a system which produces goods and services with its input, production processes (of scientific activity) and output, this can be expressed mathematically with the following form:

$S_{ors} = f\,(P, B, O, \ldots)$

where

S_{ors} = System of the scientific research bodies

P = research personnel

B = assets

O = organisation

The system of the research bodies is not identified by the sum of the three components, but is the result of their combination according to certain rules, which form the operational rules of the system. The system activity is expressed in a unitary process in which it is possible to identify the processes linked to the various complementary and interacting processes.

The first component P (research personnel) is the most important in the research units. In order to emphasise the importance of the human factor the German academic, Nicklisch (1932) stated "Der Betrieb ist der Mensch" (the company is the man). The dynamic nature of the system is above all due to this fundamental component which differs in the individual units or groups of units, according to the functions which the persons carry out within the system. Moreover, the research personnel are of great importance because they are at the base of the cognitive dynamics (the means of creation and diffusion of knowledge) of the research bodies towards the outside environment. The knowledge is born at an individual level and then amplified and multiplied within the organisational system (Nonaka, 1994). The research bodies, unlike the companies, not only create knowledge, they also transfer it at a macro level towards the world outside, where it becomes diffused knowledge for the development of the economic system.

Moving on the component B (assets) we can briefly say that it represents all the available resources apart from human resources. This includes equipment, laboratories, libraries, credit and so on. The means are acquired by the research bodies by financial grants, assigned by the State or by the management (private laboratories), which are spent in investment, operation and missions. Finally the component O (organisation) affects both the personal (P), and the material and non material resources (B); it represents the process by which the economic forces acting on the system are defined and co-ordinated in relation to the operations to be carried out in order to reach the objectives.

Analysing the system of the research bodies we find:

1. the *input* are the resources of the system which generate the cognitive process. In a research laboratory the input includes the human factor, the information, the ideas, the equipment, the libraries, the structures and the sources of financing. If the laboratory is in a company the research work is carried out on the basis of specific requests from the marketing, production, planning divisions, etc. If it is public the work carried out will follow certain independent basic research projects and will also involve commissions received from other external bodies (public administration or private bodies). Commissioned work is of considerable importance to the research bodies since it generates substantial self-financing.

2. The *production process* of a research body transforms the input into output through the realisation of research projects, training courses, service activities, etc.
3. The *output* of the research laboratories includes the publication of books, manuals, documents, reports, and projects, the issue of formulas, software programs, innovations (products, processes and organisational) and patents. These outputs come within the explicit transfer of knowledge but some studies have shown that the research bodies, in particular public ones, carry out consistent tacit activities through the diffusion of knowledge during internal training and teaching of courses outside the institute. Apart from these explicit and tacit activities the research bodies, thanks to the competence accumulated in specific areas and the availability of advanced equipment, also offer a series of innovative services such as consultancy, homologation, accreditation, calibration, certification, etc.

(Coccia, 1999a; 1999b; 1999d).

4. The *system which absorbs the output* must be differentiated according to whether it is a private or a public research body. In the first case they are principally the divisions (production, marketing, etc.) or the companies which form part of the group. In the case of public research bodies, the recipient of the transfer is more widespread and includes users which vary according to whether the output is explicit or tacit. In the case of explicit transfer the users are manufacturing industries, public administration bodies, international bodies and professionals involved in meeting needs, improving competitivity or in research which will have positive effects for society as they increase the level of wealth. In the case of tacit transfer the principal beneficiaries are the universities mainly interested in increasing the cultural level necessary to create human capital to sustain the future development of the country.

5. The *results* of the research bodies are the variables which have value for the receiving systems. If the research body is private this may be a reduction in costs, the income, new products, market shares, etc. If the research body is public it may be an increase in the cultural level, the solution to social problems (economic growth, reduction of unemployment, …), increased competitivity in the national industrial system, etc.

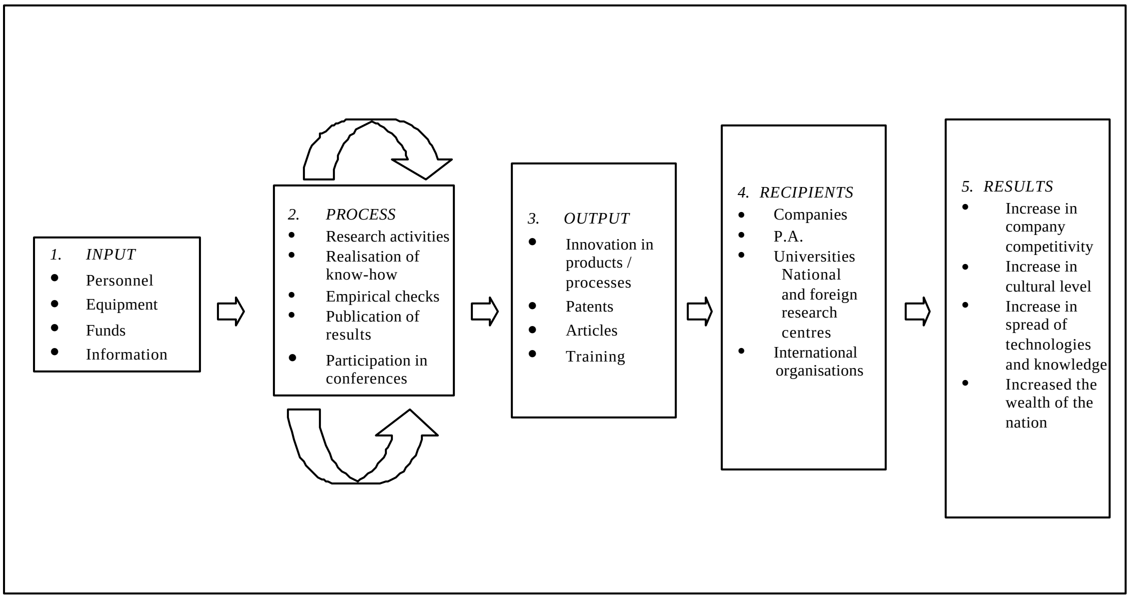

Figure 1. The production system of the research bodies

Source: Ceris-Cnr (1999).

The measurement and evaluation of the public and private research bodies is based on their output, considering three dimensions: cost, quantity and quality. Considering these three variables shows the real added value which a research body pours into the receiving systems. The ideal evaluation system according to Brown and Svenson (1998) should:

- have external, not internal measures
- focus on outcomes, not on behaviour
- measure output by three dimensions: cost, quantity and quality
- be simple (6 - 7 indices)
- be mainly objective and not subjective

The present work has created the *relev* method (**re**search **l**aboratories **ev**aluation) based on the fact that the activity of each unit (research laboratory) is measured by k-indices (X_1, X_2, X_3,… X_k) which fit mathematically into a multidimensional space, thanks to the vector of the values (x_1, x_2, x_3,… x_k). Utilising a linear combination function we have a new variable **W** which represents the score of the performance of the bodies evaluated.

The linear combination function takes the form of:

$$\mathbf{W = d_1X_1 + d_2X_2 + d_3X_3 + \ldots + d_kX_k}$$

where:

Ω = the value of each unit (Laboratory)

δ_i = scalar values

Xi = indices (i = 1,2, …, k)

In this work, after the introduction, the indices used in the systemic evaluation of performance will be described (section 2). Sections three contains a theoretical description of the methodology elaborated for the global evaluation of the activities of the R&D laboratories. Section 4 empirically applies the study to a concrete case represented by the nine CNR Institutes operating in Piedmont (Italy) and belonging to different research areas (economic, environmental, technological, etc.). The research closes with a series of conclusions and considerations on possible future evolution of the research (section 5).

2. Indices for measurement of the research activities

The scientific performance of the research bodies is measured by a series of seven indices which are grouped in four categories that consider all the aspects of the life of the R&D bodies, from the financial to the technological and the scientific.

- The financial indices measure two aspects: the dependence of the research bodies on the external commissions and their capacity for self-financing, the latter is also an indicator of the strength of explicit technological transfer.
- The indices of tacit transfer measure the capacity of the bodies to transfer knowledge in an informal manner.
- The bibliometric indices measure the capacity of the bodies to produce scientific articles, at both national and international level, on basic and applied research topics.
- The technometric index shows the capacity of the bodies to produce product and process with patent activities.

We will now examine the various indices in detail (from now on the terms "laboratory" and "research body" are used with the same meaning).

2.1. Financial indices

A= Index of funding attributed to the research bodies

Each research body receives funding by means of transfers from the central body. In order to evaluate the dependence of the research bodies on the funds, the amounts are divided, in each laboratory, by the research personnel in the year in question. The index of financial dependence, in monetary value has the following formula.

$$\alpha_i = \frac{D_i}{P_i} \times 100$$

where:

α_i = Index of financial dependence of the body i-th

D_i = $\sum_{ij}$ (sum) in the body i-th of the j funds from the central body.

P_i = $\sum_i$ number of research personnel in the body i-th

$i \in \{1,2, \ldots, n\}$

$j=1,2,\ldots, m$

This index shows the volume of financial resources supplied to the laboratory by the central body for carrying out scientific research.

B = Index of self-financing (measure of explicit technological transfer)

The laboratories' effective capacity for self-financing is evaluated by means of the revenue generated by the activities of technological transfer divided by the research personnel in the year in question. The index of self-financing has the following formula:

$$\beta_i = \frac{E_i}{P_i} \times 100$$

where:

β_i = Index of self-financing of the laboratory i-th

E_i = $\sum_{ij}$ (sum) in the body i-th of the j income deriving from the transfer of technological activities towards external subjects.

P_i = $\sum_i$ number of research personnel in the laboratory i-th

$i \in \{1,2, \ldots, n\}$

$j=1,2,\ldots, m$

The present index measures the body's capacity to locate external resources (self-financing) but is also an indicator of the capacity for explicit technological transfer.

2.2. Indices of tacit technological transfer

The tacit technological transfer represents those activities which the organisations often underestimate because they are invisible and difficult to measure, but which have the same importance as formal technological transfer. The activity has been identified thanks to the following indicators (Coccia, 1999c):

– number of personnel in training operating within the bodies;
– number of teaching posts held by the researchers.

X = Index of personnel in training

The index of personnel in training χ_i, is constructed as follows:

$$\chi_i = \frac{T_i}{P_i} \times 100$$

where:

χ_i = Index of tacit transfer which measures the level of training at the laboratory i-th

T_i = $\sum_i$ number of personnel in training at the laboratory i-th

P_i = $\sum_i$ number of personnel involved in research

$i \in \{1, 2, \ldots, n\}$

The present index measures the number of trainee at the laboratory which also indicates the capacity for tacit transfer of knowledge to the beneficiaries (scholarship holders, PhDoctors, bachelor degree students, loan personnel, etc.).

D= Index of teaching activity

Another indicator of tacit activity is the measurement of teaching by researchers in outside institutions. Here the effective capacity of tacit technological transfer has been evaluated using the index (δ_i) constructed by dividing the number of courses held by the research personnel.

The formula of the index is:

$$\delta_i = \frac{C_i}{P_i} \times 100$$

where:

δ_i = Index of tacit transfer measured using the teaching courses of the laboratory

C_i = $\sum_i$ number of courses held by laboratory researchers in outside institutes

P_i = $\sum_i$ number of research personnel

$i \in \{1,2, \ldots, n\}$

The present index measures the entity of the courses held by the bodies. Like the previous index it is an indicator of the capacity for informal transfer of knowledge through researcher’s teaching activities at outside institutes (Universities, post-graduate schools, etc.).

2.3. Bibliometric indices

E *= Index of national publications*

The present index is calculated by adding the number of articles published in national journals, books published by Italian publishers, publication of the acts of national congresses and internal reports published by the body. The total number is divided by the total of the research personnel.

$$\varepsilon_i = \frac{PN_i}{P_i} \times 100$$

where:

ε_i = Index of the body’s national publications

PN_i = $\sum_{ij}$ (sum) in the laboratory i-th of the national publications

P_i = $\sum_i$ number of research personnel of the body i-th

$i \in \{1,2, \ldots, n\}$

j=1,2,…, m

F*= Index of the international publications*

The present index is calculated by adding the number of articles published in international journals, books published by foreign publishers and publication of the acts of international. The total number is divided by the total of the research personnel.

$$\phi_i = \frac{PIT_i}{P_i} \times 100$$

where:

ϕ_i = Index of the international publications by the laboratory i-th

PN_i = $\sum_{ij}$ (sum) in the laboratory i-th of the j international publications

$P_{3\,i}$ = $\sum_i$ number of research personnel in the laboratory

$i \in \{1,2, \ldots, n\}$

j=1,2,…, m

2.4. Technological index

G*= technometric index*

The index is the sum of the number of patents for inventions of discoveries (homologated and extended to different countries) by laboratory personnel.

$$\gamma_i = BR_i$$

where:

γ_i = Technometric index of the laboratory i-th

BR_i = $\sum_{ij}$ (sum) in the laboratory i-th of j patents

$i \in \{1,2, \ldots, n\}$

$j=1,2,\ldots, m$

3. The *relev* method

The *relev* methodology evaluates the performance of the research bodies (central topic of the inquiry is the research bodies) on the basis of measurement of *k-key indices* representing the principal activities carried out. The seven indices previously described are to be considered elements of a whole $\Im$ associated with a giant research body. The basic model is kept fairly simple in order to contain the subjectivity within certain limits. Before moving on to an explanation of the methodology we will explain some definitions and the theoretical basis of the model.

Definitions

Evaluation is the determination of the value, as objective as possible, to be assigned to an organisation with the aim of stating a judgement or creating a classification of efficiency and efficacy in pursuing the aims set.

Performance gives the idea of the value of the organisation over an interval of time in carrying out activities.

Score is the sum of the points assigned and gives the value of the organisation in carrying out its activities.

Knowledge scoring: score which expresses the research bodies capacity for producing knowledge, generally obtained by following an analytical path based on the final balances of the activities carried out.

Presuppositions

The following hypotheses are the theoretical basis for the model:

- The research body is a system of interacting and co-ordinated material and non-material elements for the production of knowledge (purpose), raw material for increasing the social wealth of the nations.

- The weight of each index is the maximum value of the same in the vector and is calculated on a battery of structures operating in the same research area.
- The maximum value of the index shows the best performance.
- The index of financial dependence on the central body has a non-positive effect on the performance since these are resources not generated within the structure.
- The capacity for self-financing, publications and patents, training personnel and teaching outside the Institute has a positive effect on the performance of the structure. The operators are marked by the plus sign (+).
- Since international publications generate greater diffusion of knowledge they are given double weighting with respect to those published nationally.

The **r**esearch **l**aboratories **ev**aluation *(relev)* methodology is constructed on the basis of the following steps: the first is to calculate the seven indices for each research body and construct seven tables by ranks, one for each index, with values in decreasing order from the top to the bottom.

Both TA the table relative to Index $A = (\alpha_1, \alpha_i, \ldots, \alpha_n)$ where α are the values obtained for each body per i =1, …, n (e.g. nine).

Table TA

Laboratory i	Absolute value α_i
1	α_1
…	…
…	…
N	α_n

Each classification contains *n* values for each laboratory. The present table is constructed using six other indices $B = (\beta_1, \beta_2, \ldots, \beta_n)$, $X = (\chi_1, \chi_2, \ldots, \chi_n)$, $\Delta = (\delta_1, \delta_2, \ldots, \delta_n)$, $E = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n)$, $\Phi = (\phi_1, \phi_2, \ldots, \phi_n)$, $\Gamma = (\gamma_1, \gamma_2, \ldots, \gamma_n)$.

The values of these indices are used in the construction of the *relev* function, a linear combination which summarises quantitative, qualitative and cost aspects (second step).

Model

We consider the seven indices, with the respective values of the *n* R&D bodies :

$A = (\alpha_1, \alpha_2, \ldots, \alpha_n)$

$B = (\beta_1, \beta_2, \ldots, \beta_n)$

$X = (\chi_1, \chi_2, \ldots, \chi_n)$

$\Delta = (\delta_1, \delta_2, \ldots, \delta_n)$

$E = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n)$

$\Phi = (\phi_1, \phi_2, \ldots, \phi_n)$

$\Gamma = (\gamma_1, \gamma_2, \ldots, \gamma_n)$

The model is developed according to the following simple function:

Relev function

Let $i \in \{1, 2, \ldots, n\}$ equal the number of research bodies, let A, B, X, Δ, E, Φ, Γ equal the evaluation indices with the respective elements ($\alpha_i, \beta_i, \chi_i, \delta_i, \varepsilon_i, \phi_i, \gamma_i$). The **re**search **l**aboratories **ev**aluation function Ω_{relev} is the following linear combination:

$$\Omega_{relev}(i) = 3 - \left(\frac{1}{\max A}\right)\times\alpha_i + \left(\frac{1}{\max B}\right)\times\beta_i + \left(\frac{1}{\max X}\right)\times\chi_i + \left(\frac{1}{\max \Delta}\right)\times\delta_i + \left(\frac{1}{\max E}\right)\times\varepsilon_i + 2\left(\frac{1}{\max \Phi}\right)\times\phi_i + \left(1 \;\; se \;\; \gamma_i \geq 0; \;\; 0 \;\; se \;\; \gamma_i = 0\right)$$

If

$X_1 = (1 / \max. \boldsymbol{A}) \times \alpha_i$

$X_2 = (1 / \max. \boldsymbol{B}) \times \beta_i$

....

$X_7 = (1 \text{ se } \gamma_i \geq 1; \;\; 0 \text{ se } \gamma_i = 0)$

then

$$\mathbf{W}_{relev}\ \mathbf{(i) = 3 - X_1 + X_2 + X_3 + X_4 + X_5 + 2\ X_6 + X_7}$$

Property 1

If $i \in \{1, 2, \ldots, n\}$ e $j \in \{1, 2, \ldots, 7\}$, $\forall X_j \in \Omega_{relev}$ (i) then $X_j \in [0,1] \subseteq \Re$,

Property 2

If $i \in \{1, 2, \ldots, n\}$ e $j \in \{1, 2, \ldots, 7\}$; $\forall X_j \in \Omega_{relev}$ then Ω_{relev} (i) max. = 10

(Ω_{relev} (i) min = 2)

Property 3

If $i \in \{1, 2, \ldots, n\}$ e $j \in \{1, 2, \ldots, 7\}$; $\forall X_j$ then Ω_{relev} (i) average = max − min / 2

A model (0,1) is applied to the vector Γ, that is the value 1 if the number of patents is at least 1, the value 0 if there are no patents; the reason for this is to avoid penalising research bodies operating in the social or mathematical sciences which do not produce patents as do the other sciences (physics, chemistry,...).

Finally, on the basis of the values deriving from the evaluation function Ω_{relev} = ($\omega_1, \omega_2, \ldots \omega_n$) a table of classification is drawn up (Table 8), in decreasing order from the top to the bottom, where each position represents the performance of the scientific activities of the research bodies.

4. An empirical application of the *relev* method on the CNR Institutes present in the Piedmont region

The validity of the *relev* methodology was tested on the CNR Research Institutes operating in Piedmont, bodies recognised at an international level for their research activities in two major areas: technology and its industrial uses, economy and environment. The data has been taken from the final reports of the Institutions for the years 1995, 1996, 1997. Before analysing the results which emerged from the methodology, for greater clarity, it is considered necessary to briefly describe the activities of the Institution and of the individual institutes in Piedmont.

The *Consiglio Nazionale delle Ricerche Italiano* (CNR) is the largest Italian public research institute with the institutional objective of promoting, co-ordinating and organising research in order to encourage scientific and technological progress. The institutional scientific activity is mainly carried out through the Institutes, research bodies which are totally dependent on the CNR. Nine CNR Institutes operate in Piedmont, a highly industrialised region in north western Italy, covering two major areas of research: technology and its industrial uses and environment. The most important research sectors carried out at the four Institutes belonging to the technological area are:

- metrology and its application to advanced technology and properties of materials: Istituto di Metrologia "G. Colonnetti" (IMGC);
- metal machinability: Istituto per la Lavorazione dei Metalli (ILM);
- technology in the working processes of the wool industry: Istituto di Ricerche e Sperimentazione Laniera "O. Rivetti" (IRSL);
- the application of mechanisation and automation to agricultural processes: Istituto per la Meccanizzazione Agricola (IMA).

The Institutes belonging to other areas (agriculture, environment, geology, physics and economy) carry out the following research:

- diagnosis and control of viral plant disease: Istituto di Fitovirologia Applicata (IFA);
- monitoring of environmental conditions in the lakes by the Istituto Italiano di Idrobiologia "M. De Marchi" (I I I) and of the atmosphere by the Istituto di Cosmo-Geofisica (ICGF);
- the study methods in the geological-morphological field finalised in the forecasting and prevention of landslides and floods: Istituto per la Protezione Idrogeologica nel Bacino Padano (IRPI);
- the study of applied economics and industrial organization: Istituto di Ricerca sull'Impresa e lo Sviluppo (CERIS).

The CNR Institutes have the following types of input:

- funding from the headquarters in Rome
- resources from contacts with outside subjects (self-financing)
- research and technical personnel
- equipment and instrumentation
- libraries and laboratories

The principal outputs, fruit of the scientific production process, are (Coccia, 1999a) shown in Figure 2:

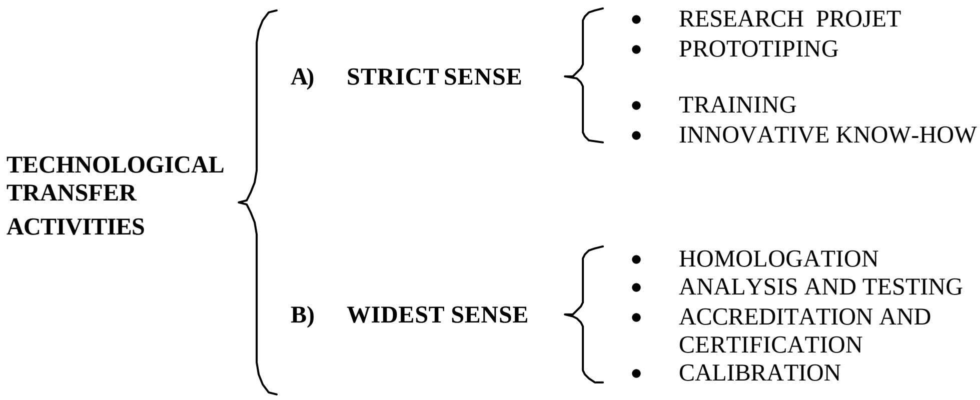

Figure 2. Technological transfer activities carried out by the Cnr Institutes operating in Piedmont

Source: Ceris-Cnr (1999).

The *relev* method, as described, first calculates the tables of the indices. Since seven indices are considered here (every index is related to the number of research personnel at the Institute, in order to allow homogeneous comparison), there will be seven tables (1-7) each showing the values (α, β, χ, δ, ε, ϕ, γ) of the various Institutes.

The first index, A, represents the funding supplied to each Institute by the headquarters in Rome. The relative Table is:

Table 1

Institutes	Funding (*)	Personnel (1)	Index A
IRPI	1,001.8	59	17
IMGC	5,119	297	17.2
ILM	864.5	50	17.3
IMA	1,610.2	85	18.9
III	2,640.5	121	21.5
IFA	2,004	89	22.5
IRSL	1,035	37	28
CERIS	1,763.4	51	34.6
ICGF	3,210	93	34.9

(1) Research personnel at the institute, except for outside personnel and trainees

(*) Values × 1,000,000 in Italian lira; 1936,27 Italian lira = 1 Euro

Source: Ceris-Cnr (1999).

The Index B shows the capacity for self-financing. The values for the various Institutes are:

Table 2

Institutes	Self-financing(*)	Personnel (1)	Index B
IRSL	1,198,289	37	32,386
IMGC	5,586,599	297	18,810
III	1,806,008	121	14,950
IMA	1,212,354	85	14,263
ILM	580,937	50	11,618
IRPI	412,490	59	6,991
CERIS	259,125	51	5,080
ICGF	390,893	92	4,249
IFA	337,355	89	3,790

(1) Research personnel at the institute, except for outside personnel and trainees

(*) Values × 1,000 in Italian lira; 1936,27 Italian lira = 1 Euro

Source: Ceris-Cnr (1999).

Following the financial indices, we move on to the indices which express the Institutes' capacity for tacit transfer of knowledge. The index X is an indicator which expresses the personnel in training in each Institute:

Table 3

Institutes	Trainee	Personnel (1)	Index X
IRPI	34	35	97
CERIS	38	42	90
IRSL	15	22	68
III	39	64	61
IFA	22	38	58
ICGF	60	106	56
IMGC	63	113	56
IMA	10	23	43
ILM	6	14	43

(1) Research personnel employed at levels I, II, III, personnel on contract and outside personnel

Source: Ceris-Cnr (1999).

The index Δ is another indicator of tacit transfer and indicates the number of courses held by the researchers at outside institutes:

Table 4

Institutes	Courses held by researchers	Personnel (1)	Index D
IMGC	123	113	109
CERIS	44	42	105
III	55	64	86
IFA	22	38	58
IRPI	20	35	57
ICGF	55	106	52
IMA	7	23	30
IRSL	1	22	4
ILM	0	0	0

(1) Research personnel employed at levels I, II, III, personnel on contract and outside personnel

Source: Ceris-Cnr (1999).

The index E is a bibliometric index which represents the number of publications produced in the national sphere by the personnel of each Institute.

Table 5

Institutes	Number of national articles	Personnel (1)	Index E
CERIS	169	51	3.31
IRPI	159	75	2.12
ICGF	151	93	1.62
IMA	105	90	1.16
IRSL	33	37	0.89
IMGC	258	297	0.86
ILM	40	50	0.80
III	97	123	0.78
IFA	57	89	0.64

(1) Research personnel at the institute except for personnel belonging to other organisations (e.g. universities)

Source: Ceris-Cnr (1999).

The index Φ, is a bibliometric index which represents the number of publications produced by the research personnel of each institute in the international sphere.

Table 6

Institutes	Number of international articles	Personnel (1)	Index F
ICGF	209	93	2.24
III	125	123	1.01
IFA	57	89	0.64
ILM	37	50	0.74
IMGC	117	297	0.39
IRPI	29	75	0.38
CERIS	14	51	0.27
IMA	18	90	0.20
IRSL	3	37	0.08

(1) Research personnel at the Institute, except for personnel belonging to other organisations (e.g. universities)

Source: Ceris-Cnr (1999).

The index Γ, is a technometric index, representing the capacity of the various Institutes to realise innovation of products and processes measured by the number of patents taken out during the three year period.

Table 7

Institutes	Number of patents
IMGC	1
IMA	1
III	1
CERIS	0
IFA	0
IRSL	0
ICGF	0
ILM	0
IRPI	0

Source: Ceris-Cnr (1999).

The performance evaluation function for the Institutes (*relev*) is formed of eight operators, at the start of the function the value 3 is used to obtain maximum values of 10, to avoid expressing the maximum with another value. The second operator is negative since it represents financing of the Institutes by the headquarters. The penultimate operator is multiplied by two because it represents international publications and it was therefore considered desirable to give it greater qualitative weight with respect to national publications. In this special case, I prefer to take the max value of the index considering all research bodies and not structures operating in the same research area because there are only four technological Institutes and five Institutes belonging to other different areas (agriculture, environmental, geology, physics and economics).

The operators from the second to the eighth have a range between 0 (minimum) and 1 (maximum).

The *relev* function, empirically calculated is:

$$\Omega_{relev}(i)=3-\left(\frac{1}{34.9}\right)\times\alpha_i+\left(\frac{1}{32{,}386}\right)\times\beta_i+\left(\frac{1}{0.97}\right)\times\chi_i+\left(\frac{1}{1.09}\right)\times\delta_i+\left(\frac{1}{3.31}\right)\times\varepsilon_i+2\left(\frac{1}{2.24}\right)\times\phi_i+\left(1\;\; se\;\; \gamma_i\geq 0;\;\; 0\;\; se\;\; \gamma_i=0\right)$$

The value obtained from the function for each Institute, knowledge scoring, is summarised in the following table 8:

Table 8

INSTITUTES	FUNCTION	KNOWLEDGE SCORE
III	3-0.61+0.46+0.62+0.78+0.23+0.9+1	6.38
IMGC	3-0.49+0.58+0.57+1+0.25+0.34+1	6.25
ICGF	3-1+0.13+0.57+0.47+0.48+2+0	5.65
CERIS	3-0.99+0.15+0.92+0.96+1+0.24	5.28
IRPI	3-0.48+0.21+1+0.52+0.64+0.32	5.21
IMA	3-0.54+0.44+0.44+0.27+0.35+0.16+1	5.12
IFA	3-0.64+0.11+0.59+0.53+0.19+0.86	4.64
IRSL	3-0.8+1+0.70+0.03+0.27+0.08	4.28
ILM	3-0.49+0.35+0.44+0+0.24+0.66	4.20

Source: Ceris-Cnr (1999).

Table 9

Institutes	Y Score	X Average number of Employees (1)
IMGC	6.25	137
III	6.4	62
CERIS	5.3	31
IRPI	5.2	31
IMA	5.2	36
ICGF	5.65	66
IRSL	4.3	20
IFA	4.6	42
ILM	4.2	21

(1) The average value is obtained by considering the total number of employees at the institute in the three year period (1995 - 1996 - 1997) including personnel in training

Source: Ceris-Cnr (1999).

The statistical-econometric study which follows aims to investigate the way in which the variable “human resources” influences the growth in performance. The Table

9 shows the knowledge score attained by the Institutes, in the second column, according to the *relev function* (Table 8) and the average number of employees in the three year period (1995 - 1997), in the third column.

The first statistical analysis carried out is the correlation between the two variables X and Y with the *coefficient of correlation r* given by the following formula:

$$r = \frac{\sum_{i=1}^{n} x_i y_i}{\sqrt{\sum_{i=1}^{n} x_i^2 \cdot \sum_{i=1}^{n} y_i^2}}$$

The value of *r* is the result equal to 0.75 and shows a strong positive correlation between the two variables: as the variable X grows there is a linear growth of the variable Y.

Considering the score as a dependent variable (Y) and the average number of employees as an independent variable (X), we proceed with an econometric analysis with the simple regression model.

The equation of the model is the following

$$Y_i = \alpha + \beta X_i + \varepsilon_i \qquad i = 1, \ldots, n$$

The plotter of the values obtained in the estimate of the relation between Y and X is shown in Figure 3:

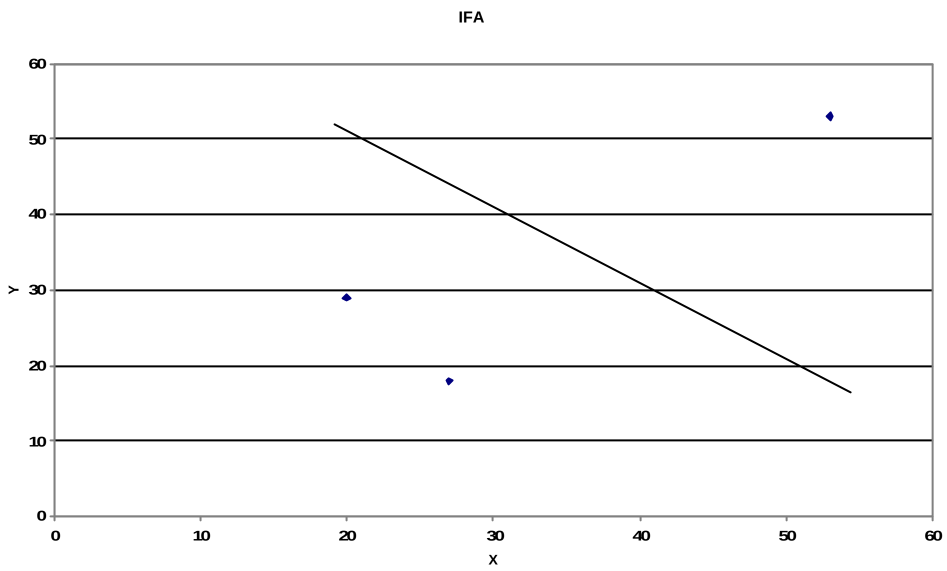

Figure 3. Score as a function of the employees (period 1995 - 1997)

Source: Ceris-Cnr (1999).

The analysis of the regression gave the following results:

α= 4.436

β= 0.016

From both the graphic analysis and the angular coefficient β we note the growing trend in the relation between the two variables in question. The validity of the model of linear regression is evaluated with the coefficient of determination R^2 given the relation between the variation explained and the total variation.

That is

$$R^2 = 1 - \frac{\sum e_i^2}{\sum y_i^2}$$

It has the following range of value $0 \leq R^2 \leq 1$. The model has shown $R^2 = 0.56$ which confirms that the variable X, average number of employees, explains 56% of the total variation; the efficiency of the model could increase if other variables at present unknown are considered. Moreover on observing Table 9 we note the following behaviour of the Institutes:

- with an average number of employees > 60, the Institutes tend to be positioned in the upper part of the classification;
- with a number of employees ≤ 21, the Institutes tend to be in the lower part of the classification;
- with an average value (av) between 22 < av ≤ 60, the Institutes tend to be positioned at variable levels, oscillating between medium-high positions (CERIS, IRPI, IMA) and average to low (ICGF, IRSL, IFA), which confirms the influence of factors other than personnel on performance.

From the above statistical-econometric analysis we note that the component personnel is very important inasmuch as it contributes to increasing the performance of the CNR Institutes. The human resources and their organisation create an environment which positively influences the spiral of creation of knowledge (cognitive processes); moreover the network relations, between the members of the structure encourage the circulation of the same within it generating the so-called phenomenon of *cross-fertilisation* with considerable benefits for the outside environment. A complete study of the importance of the human component in the cognitive processes and in the increase in the efficiency of the research bodies would require the involvement of many disciplines amongst which economics, psychology, law, sociology, etc. and would be worth going into in the future.

5. Conclusions

The aim of the work was to create an objective methodology for the evaluation of performance in the R&D laboratories. Using a systemic approach, that is considering the research laboratory a set of forces interacting to reach the aim of producing knowledge, the *relev* method has been created considering the complexity of the activities carried out in the research structures.

The methodology has evaluated the performance of the institutes considering the financial (funding and self-financing), scientific (national and international articles) and technological aspects (explicit and tacit). The method has a simple formulation and the *relev* function, being a linear combination of seven indicators of evaluation, summarises in a single value (the knowledge score) the performance of the research body examined in consideration of quantitative, qualitative and cost aspects. In the method the cost aspect is considered on the basis of funding received from central bodies, the quantitative aspect, on the other hand, is considered on the basis of revenue deriving from the activities directed the outside (monetary value) and the publications and patents held the research body (numerical values); the qualitative aspect is based on the attribution of a double weight of international publication with respect to national ones. The methodology is applied to nine CNR Institutes operating in Piedmont and the results obtained have been summarised in a decreasing classification, where the Institutes with a higher level of performance are at the top and those with a lower level of performance are at the bottom. The analysis of the Institutes is completed by the statistical-econometric application to assess how far the score obtained from the *relev* function in the various Institutes depends on the number of employees (independent variable). The model of regression has estimated a straight line with $\beta = 0.016$ and highlighting an R^2 greater than 0.56 which shows that the linear relation of growth is explained for more than 56% by the number of employees. The index *r (coefficient of correlation)* has shown a value of 0.75 evidencing the importance of the human resources in the process of scientific research.

The construction of the *relev* methodology has deliberately emphasised the simplicity of the model, based on seven key indicators, and the minimising of the subjectivity obtained thanks to the increased weight of the quantitative and economic measures as against the qualitative. In support of this formulation it must be noted that the increased weight given to the quantity and to the costs is born of the fact that the aim was to measure the performance of the research bodies, considering them the main topic of the inquiry, while the qualitative aspect is more important when evaluating the individual researchers. A future development in the research could certainly be the inclusion of two qualitative variables, with the analysis of the citations and the co-citations of the Science Citation Index of the Institute for Scientific Information (ISI), which would not complicate the model excessively and would maintain the area of subjectivity within acceptable limits.

Evaluation
is the determination of the value, as objective as possible, to be assigned to an organization with the aim of starting a judgement or creating a classification of efficacy and efficacy in pursuing the aims set.

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