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Developing a performance measurement system for public research centres

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Abstract

This study aims at developing a performance measurement system (PMS) for research and development (R&D) activities carried out by public research centres. Public research institutions are characterized by multiple stakeholders with different needs, and the management of R&D activities requires balancing the multiple goals of different stakeholders. This characteristic is a key issue in the process of construction of the PMS. Empirical evidence is provided by an Italian public research centre, where the researchers carried out a project aimed to develop a PMS following action research principles. This project gave the possibility to researchers to interact with different stakeholders and integrate their different information needs in a comprehensive set of key performance indicators (KPIs). As a result, multidimensional framework for measuring R&D performance in a public research centre is proposed and a set of Key Performance Indicators is developed, suggesting implications for academics and practitioners.

Keywords: performance measurement, public research centres, stakeholders, accountability, decision-making

1 INTRODUCTION

In recent years public research systems in several industrialized countries, underwent an intense transformation process due to the increasing organizational complexity of research & development (R&D) activities and the hit of the worldwide financial crisis. Leading research institutions claim that many complex problems of the society demand innovative solutions which combine knowledge from different scientific areas that can be achieved through interdisciplinary research (National Academies, 2005). To achieve this, very often, research centres carry out interdisciplinary R&D projects, which require collaborative and sometimes informal behaviours (Cross, Borgatti and Parker, 2002; Allen, James, & Gamlen, 2007) and new forms of organization and management (Welter, Jooß, Richert, Jeschke, & Brecher, 2012). At the same time, the financial crisis has reduced the overall government spending and specifically the budget for research centres (e.g. Arena &Arnaboldi, 2013). This reduction of funding has increased the competition between research institutions, while at the same time they are required to demonstrate their value for money. To face these challenges, research institutions need to consciously manage their core processes, the creation and development of their knowledge assets (Rowley, 2000), and consistently redesign their support processes and managerial instruments (e.g. Arena, Arnaboldi, Azzone & Carlucci, 2009; Arena, Arnaboldi & Azzone, 2010a;Welter et al. 2012).

In this context, our paper focuses on one specific managerial instrument - i.e. performance measurement system (PMS). In the last decades, measuring R&D performance has become a fundamental concern for R&D managers and executives. Scholars and practitioners have already recognized the relevance of performance measurement in R&D in relationship to different purposes (e.g. Chiesa, Frattini, Lazzarotti&Manzini, 2009; Kulatunga, Amaratunga&Haigh, 2011). A PMS can be useful for motivating researchers, evaluating R&D projects' profitability, supporting decision-making, communicating the centre's results to external constituencies, and stimulating organizational learning.

However, most of the current research about PMS in R&D focuses on private sector organizations (e.g. Bremser&Barsky, 2004; Chiesa et al., 2009) and these results are not easily applicable to Government-funded research centres, since they overlook some key characteristics of these organizations. In industrial firms, R&D activities are primarily financed by the company itself and they represent one of the activities in their value chain. In this context, the company does not have the need of searching for research funding, given that it is self financed and research outputs represent the input for further processes of the firm's value chain. The research results are incorporated into products and, in the end, brought to the market and sold by the company, 'hopefully' resulting in an increase in the revenue and profits of the firm, and contributing amortize the R&D investment. On the contrary, in Government-funded research centres, such as public research institutions, the research activity represents the core mission of the organization and the R&D activity needs to be financed by external parties. This structure has two main implications. On the one hand, the role played by the research activity is central, because the output of the research represents the end itself. Research institutes contribute to the early stages of the innovation process of various customers within the national innovation system and serve thus as an important research infrastructure, (Shenker, 2001; Leitner & Warden, 2004). On the other hand, the need for searching funding is associated with the pressure of demonstrating the ability of generating research outputs that provide value for the society. The output of public research centres is expected to have a positive impact on the wider society; their principal aim is to disseminate the research results and to have a return in terms of scientific-technological progress, driving the national strength (Senker, 2001; Coccia, 2004). However, once the funding are received, mainly by the public government (Senker, 2001; Coccia, 2004), the research centre has to be accountable on how it spend public money. In this sense, Coccia (2005) argued that research institutions are dependent on the government for carrying out their activities. As consequence of these specificities, public research centres are subject to different and contrasting stakeholders pressures that are wider compared to private sector organizations (Dixit, 2002; Coccia, 2004; Arnaboldi, Azzone & Savoldelli, 2004). Public government, the wider society, the researcher, the administrative manager but also private partners, have different objectives and their alignment can be extremely complex, especially in the current R&D landscape characterized by reduced finance and higher competition between institutions.

To our best knowledge, relatively a few contributions have dealt with the issue of R&D performance measurement in the public sector (e.g. Coccia, 2001a; 2004; Leitner & Warden, 2004; Secundo, Margherita, Elia & Passiante, 2010) and a comprehensive framework for measuring performance of public research institutes is still missing, setting the motivation for this work. This paper has the objective to develop a performance measurement system (PMS) for a public research centre. The centre has to deal with the informative needs of a diversified range of stakeholders that require accountability in relationship to the centre's activities and, in particular, the use of funding, but also aim to encourage collaboration between different research units and support decision making processes. The PMS has been developed through action research, whereby the researchers interacted with different stakeholders and integrated their different information needs to a comprehensive set of key performance indicators (KPIs). Interviews and meetings with scientific and administrative directors over a time horizon of ten months were useful for designing a dashboard for public research institutions that integrates the information needs of a plurality of stakeholders.

The paper is organized as follows. The next section outlines the state of the art on the issue of performance measurement for R&D activities. The third section details the methodology used for data collection and analysis, describing the phases of the research project. The fourth section presents the PMS framework and the set of indicators that have been developed. Finally, the last section clarifies contributions and limitations of this research.

R&D performance measurement in research centres

Various studies on public research centres show a growing interest in R&D performance measurement (Luwel, Noyons & Moed, 1999; Senker, 2001;Coccia, 2004; Coccia & Rolfo, 2007). Originally, particular attention has been given to the use of bibliometric and technometric indicators to evaluate public research centre performances (e.g. Narin & Hamilton, 1996; Luwel et al., 1999; Noyons, Moed & Luwel, 1999). Bibliometric involves the quantitative analysis of the scientific and technological literature. It relies on the assumption that the frequency with which a paper or a patent is cited is a measure of the impact of the paper or patent. The most common bibliometric indicators are literature indicators – i.e. indicators that measure the scientific performance based on the number of publications and the count of citations in the scientific literature, and, obviously, the higher the better. Similar considerations are applicable to patents too. Those patents which are most highly cited and most science linked are also the patents that tend to be most heavily licensed, and are therefore making the largest contribution to the economy (Narin & Hamilton, 1996).However, bibliometric indicators provide a partial and non-systemic picture of the performance of a research centre, because they overlook some relevant elements such as the impact of the research activity on the society and they ignore the role played by government funding (Coccia, 2004).

Moving from these considerations, Coccia proposed a weighted index to provide a synthetic measurement of public research's activities - Relev Model I and Relev Model II - (Coccia2001b; 2004, 2005). The Relev Model is based on an input-output model, where inputs consist in public funds, personnel payrolls and cost of labour, and outputs are represented by self-financing deriving from activities of technology transfer, training (e.g. number of degree students, PhD students), teaching (measured as the number of courses held by researchers), international and domestic publications, international and domestic conference proceedings. Based on a weighted input – output ratio, the Relev model attempts to synthesize the performance of public research centres in a unique score. This score has the final objective to support external accountability, providing evidence of the value for money generated by these institutions. Indeed, these studies generally adopt one specific perspective. They reflect the aim of governments to define metrics that could be used to assess the research centres performances in order to facilitate the identification of the most and the least productive laboratories, and to support policy decisions on the level and the direction of the public funding of research (Coccia, 2004). These kinds of metrics, instead, are less useful to support internal decision making and report a centre's performances to a broader range of stakeholders.

To respond to this need, a few studies started to focus on the use of key performance indicators for assessing R&D results in public sector research centres (e.g. Leitner & Warden, 2004; Chu, Lin, Hsiung & Liu, 2006; Secundo et al., 2010). This stream of research is based on Intellectual Capital reporting models (e.g. Stewart, 1997; Edvinsson & Malone, 1997). At a general extent, the Intellectual Capital encompasses three components: human capital, structural capital, and relational capital. The human capital refers to the characteristics of the entire organization's staff and management. The structural capital refers to organizational infrastructure. The relational capital refers to the establishment, development and maintenance of relationships with external stakeholders. The combination and integration of these forms of capital determines the entity's results that include both economic performances and other intangible results, such as research- and society-oriented results (Leitner & Warden, 2004). These approaches to performance measurement provide a more complete picture of the resources available to research centres, however they seem to overlook the performances of the centres in the transformation process of inputs in outputs (e.g. they overlook issues such as efficiency and productivity).

Finally, further evidence in relationship to R&D performance measurement is provided by the private sector literature, where the topic has been investigated from two different perspectives. In particular, one stream of research focuses on the choice of the performance dimensions and the performance indicators that are best suited to the characteristics of R&D. Some of these works consist in the application of well-known PMS frameworks, such as Balanced scorecard, Skandia navigator, Intangible asset monitor, to R&D activities (e.g. Kerssens-Van Drongelen & Bilderbeek, 1999; Bremser & Barsky, 2004). Other works consist in the development of ad-hoc frameworks and set of indicators to assess the performance of R&D (e.g. Pawar & Driva, 1999; Kim& Oh, 2002; Marr, Schiuma & Neely, 2004; Mettänen, 2005). These papers can provide a reference point for the identification of performance indicators for R&D, though they are not tailored to the specific characteristics of public sector organizations. The second stream of research, instead, focuses on the strategic design of the PMS in R&D firms and addresses the relationship between the characteristics of the PMS, the objective of the PMS and contextual variables, such as type of R&D activity, industry and company's size (e.g. Kerssens-van Drongelen & Cook, 1997; Chiesa & Frattini, 2007; Chiesa et al. 2009). These papers highlight how the PMS can be configured in a different way on the basis of the objectives that it is supposed to pursue (e.g. diagnostic, motivation and coordination), hence suggesting to pose particular attention to the different objectives of the stakeholders of a research centre.

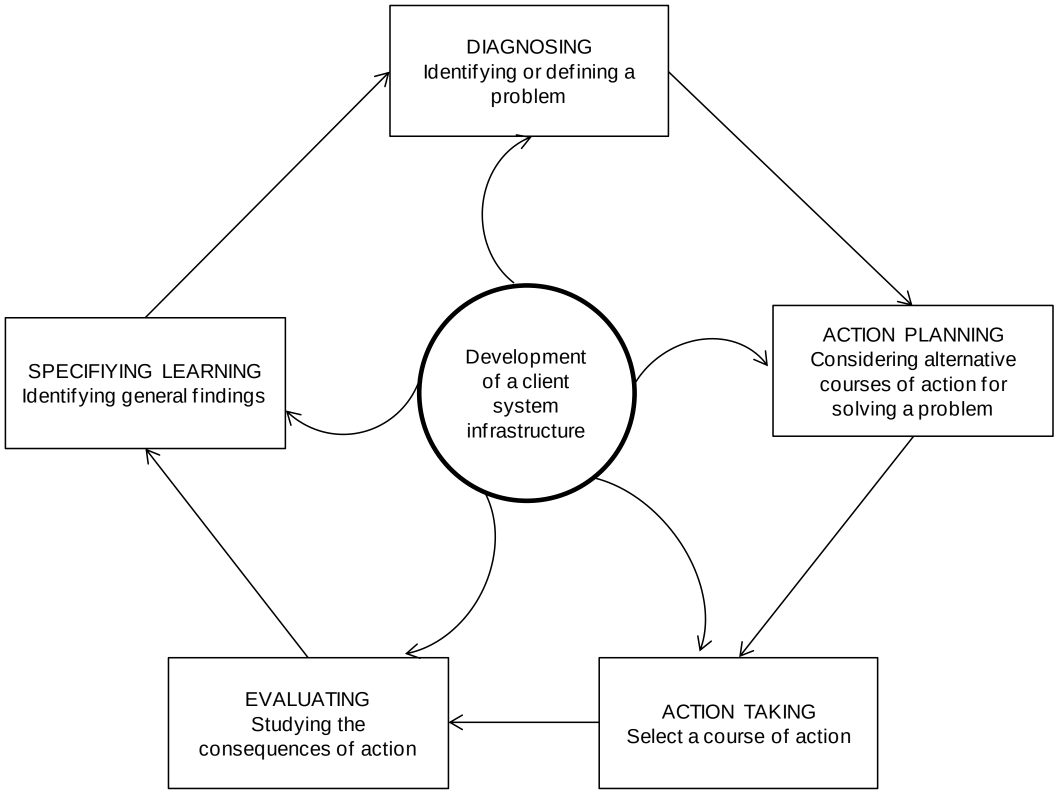
The above review has highlighted that there has been widespread dispute among researchers and practitioners about which measures are more suitable in assessing the performance of research organizations, and, at present, this debate is still open (Elmquist & Le Masson, 2009; Whelan, Teigland, Donnellan & Golden, 2010; Dumay & Rooney, 2011).

2 RESEARCH METHOD

Choice of the research method

This paper reports the results of a project aimed at developing a PMS for an Italian technological research centre. To carry out this goal we adopted action research (AR) as research methodology. Action research has been selected given its aim "to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework" (Rapoport, 1970: 499). On the one hand, this methodology gives the possibility to focus on a problematic practical situation, the need to introduce a PMS to deal with the current complex research environment that represents at the same time a relevant academic concern. On the other hand, the collaborative nature of the interaction between the researchers and the employees of the research centre allowed capturing the specific requirements from each stakeholder supporting the definition of the most appropriate set of KPIs. Specifically, we conducted AR drawing on the seminal work of Susman & Evered (1978). According to the authors, AR is seen as a cyclical process articulated in five phases: diagnosing, action planning, action taking, evaluating, and specifying learning (see Figure 1). At the centre of the cycle there is a client system that is the social system in which the members face problems to be solved by action research. Different techniques were used for data collection and analysis, including in-depth interviewing, direct observation and documental analysis (data were drown from the records, memos, and reports that the client system routinely produces). The interviews were recorded and transcribed, though the empirical material was not codified, but instead analyzed textually, with each author highlighting emergent themes. Overall 64 interviews were performed and three official plenary meetings took place; the process was highly participative (Reason & Bradbury, 2001) and different stakeholders involved continued to provide comments about the researchers' proposals.

Figure 1: The action research cycle (Susman and Evered, 1978)



The client system infrastructure

The client system is a public research centre in Italy, active in different fields of technological development. The centre currently employs more than 1,000 people, with more than 900 researchers. The centre is governed by an executive committee that defines the centre's long term strategies and is in charge of its management. It is characterized by a dual structure: the scientific director is responsible for all the research activities of the centre; the administrative director, on the other hand, is responsible for the administrative structure. The distinctive characteristic of the centre is represented by interdisciplinary R&D activities that cover several fields, ranging from robotics, neuroscience, energy, to smart materials and drug discovery. The interdisciplinary nature of the research activity is then reflected in the organizational structure that consists of 12 central research units, 11 research centres located at the premises of, and in collaboration with, other research institutions both in Italy and abroad, and 3 facilities that provide support services to the research units (e.g. animal facility).

At the beginning of the project, a working group was constituted within the client system, including the Head of the Management Control Office and a member of its staff, the Head of the ICT Office, and two internal consultants. The working group interacted with the researchers in all the phases of the AR cycles. In addition, different employees of the centre were involved as informants and prospect users of the PMS (see Table1).

Table1: The client system

Participants and informants	Organizational unit	Role in the project
Scientific Director	Central administration	Initiator and user
Administrative Director	Central administration	Initiator and user
Head of the Management Control Office	Central administration	Head of the client working group
Management and Control Office Staff	Central administration	Member of the client working group
Head of ICT Office	Administrative office	Member of the client working group
Consultant 1	External	Member of the client working group
Consultant 2	External	Member of the client working group
Head of RU 1	Research unit	Informant and user
Head of RU 2	Research unit	Informant and user
Head of RU 3	Research unit	Informant and user
Head of RU 4	Research unit	Informant and user
Head of RU 5	Research unit	Informant and user
Head of RU 6	Research unit	Informant and user
Head of RU 7	Research unit	Informant and user
Head of RU 8	Research unit	Informant and user
Head of RU 9	Research unit	Informant and user
Head of RU 10	Research unit	Informant and user
Head of RC 1	Research centre	Informant and user
Head of RC 2	Research centre	Informant and user
Head of RC 3	Research centre	Informant and user
Senior Scientist 1	Research unit	Informant and user
Senior Scientist 2	Research unit	Informant
Senior Scientist 3	Research unit	Informant
Senior Scientist 4	Research facility	Informant
Technician 1	Research facility	Informant
Technician 2	Research unit	Informant
Technician 3	Research unit	Informant
Team Leader 1	Research unit	Informant
Team Leader 2	Research unit	Informant
Head of RF 1	Research facility	Informant and user
Head of RF 2	Research facility	Informant and user
Head of RF 3	Research facility	Informant and user
Head of Research Office	Support office	Informant and user
Head of Project Office	Support office	Informant and user
Head of Technology Transfer Office	Support office	Informant and user
Head of Human Resource Office	Administrative office	Informant
Head of Engineering office	Administrative office	Informant
Head of Health and Safety	Administrative office	Informant
Head of Purchasing Office	Administrative office	Informant
Head of Legal Office	Administrative office	Informant
Head of Internal Audit Office	Administrative office	Informant
Head of Accounting Department	Administrative office	Informant

The AR Cycles

In this section we outline the phases of the two AR cycles, posing particular attention to specifying the sources used for data collection in each step of the research.

AR Cycle I

The diagnosing phase started with a literature review concerning performance measurement in research organizations, a series of project meetings and a brainstorming session on the role of the performance measurement system in the specific setting. The outcome of this phase was the identification of the process-oriented model (Pollanen, 2005) as a starting point for the development of the PMS and the acknowledgement of the existence of different information needs in relationship to the PMS from a plurality of stakeholders. Action planning consisted in mapping data and information needed to support the development of the PMS. A list of informants and relevant documentation was prepared by action researchers in collaboration with a working group of the research centre. In addition a list of critical issues (interview protocol) to be discussed with the informants was prepared. In the action taking phase, 38 interviews were carried out with the heads of scientific units and researchers of the centre, and also the administrative personnel. The analysis was complemented with public documents and confidential reports, entering in detail the scientific activity carried out by each department. Based on these data, a prototype of the PMS model and a preliminary set of KPIs were developed. In the evaluating phase the proposed model and the preliminary set of KPIs were presented in two plenary meetings, one involving the scientific director, the administrative director and a selected number of other internal officers and one involving the heads of the research units. Feedback, comments and suggestions for improvements were collected. Finally, specifying learning consisted in summing up the learning outcomes of the AR cycle. All the comments and feedbacks deriving from the evaluation phase were integrated. The outcome of this phase was twofold: the validation of the overall PMS model and an 'explosion' in the number of KPIs due the receipt of many proposals from the participants. Overall 42 indicators and several variations to each of them were suggested, posing the basis for the second AR cycle, aimed to the refinement of the set of indicators. The following table outlines the techniques used for data collection and analysis in different steps of the AR cycle, the role of the researchers and the client working group and the output produced (Table 2).

Table 2: AR Cycle I

	Techniques	**Role of the researchers**	**Role of the client working group**	**Output**
Diagnosing phase	Literature review, Project meetings, Brainstorming meetings	Challenge the informants to identify emerging issues	Contribute to the discussion	Definition of the role of the PMS in the research centre
Action planning	Literature review Project meetings	Define the agenda and design data collection tools	Support the researchers in identifying potential informants and provide feed-backs and suggestions	Design of the data collection tools to support the preparation of the PMS prototype
Action taking	Literature review Interviews Project meetings	Perform interview and data analysis	Contribute to the discussion and participate in data analysis	Development of the PMS overall model and preliminary set of indicators
Evaluating	Plenary meetings	Present the PMS prototype	Contribute to the discussion	Presentation of the PMS prototype in two plenary meetings
Specifying learning	Internal meetings	Collect and analyse feed-backs and suggestions	Support researchers in interpreting feed-backs and suggestions	Integration of feed-backs and suggestions

AR Cycle II

The diagnosing phase started with a structured analysis of the comments received concerning the set of indicators and the acknowledgement that the proposals received needed to be organized and selected. Action planning consisted in the definition of shared selection criteria to reduce the number of the indicators, still ensuring that the information needs of different stakeholders were met. To this aim, the following selection criteria were adopted: relevance, measurability, cost and timeliness (Lynch and Cross, 1991; Neely et al., 2003). In addition, to support the selection of the KPIs, a second round of 26 interviews was planned with selected informants. Action taking consisted in carrying out the interviews with an application of the selection criteria to define the new set of KPIs. For each KPI, an information protocol was prepared (see Table 4). It defines in operational terms how the indicator should be computed, the unit of measure, the level of detail, the relevance of the indicator, the frequency of data collection and the owner of these data (see also Arena & Azzone, 2010).

Table 3: The information protocol

KPI	**Number of Patents**
Definition	Number of patents distinguished by category
Computation procedure	Number of patents of the year distinguished by the following categories: First filing Extension abroad Abandoned Granted Data source: Patents database Data calculated over the following time horizon: year
Unit of measure	Units
Level of detail	Scientific structure Research unit Research team
Relevance of the indicator	This KPI evaluated the output of the research centre and its related research units in terms of patents, with respect to the different phases of a licensing process (first filing, extension abroad, abandoned and granted)
Frequency of data collection	Year
Owner of the measure	Technology Transfer Office

In the evaluating phase the results were presented in a new plenary meeting involving the scientific and administrative directors. Feed-backs we received mainly dealt with some specifications in the information protocols in the indicators, leading to new revisions. Hence, after this second round of evaluation the final set of KPIs was proposed suggesting practical directions for the research institute, but also general guidelines at the academic level (see Table 4).

Table 4: AR Cycle II

	Techniques	Role of the researchers	Role of the client working group	Output
Diagnosing phase	Project meetings	Identify key issues based on the output of the first AR cycle	Contribute to the discussion	Identification of the key issues
Action planning	Literature review, Project meetings	Define the selection criteria and design data collection tools	Support the researchers in identifying potential informants and provide feed-backs and suggestions	Design of the selection criteria and data collection tools to support the PMS revision
Action taking	Project meetings, Interviews	Perform interview and data analysis	Participate in data analysis and support the researchers in the definition of the information protocols.	Development of the final set of indicators based on the selection criteria
Evaluating	Plenary meetings	Present the final set of KPIs	Contribute to the discussion	Final presentation
Specifying learning	Project meetings	Collect and analyse feed-backs and suggestions		Practical directions for the research institute, but also general guidelines at the academic level

3 RESULTS

Results are organized in three sections. First, we introduce the overall PMS model; then, we outline different performance dimensions; finally, we present the complete list of KPIs.

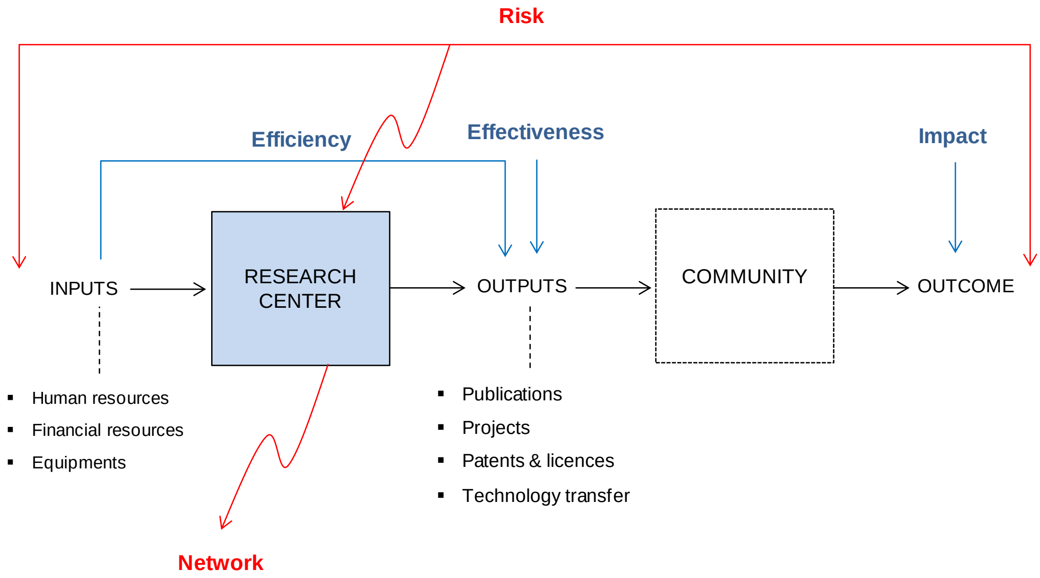
The PMS model

The starting point for the development of the PMS model is the production system process of a R&D organization. It can be represented through a process-oriented model(Brown & Svenson, 1998; Pollanen, 2005), in which research inputs are processed and transformed into output, such as publications or patents. Accordingly to this general model, performance measures can be defined on the basis of three interrelated elements: input, output and outcome. Input refers to the amount of resources used in performing a certain activity; output refers to the result of a transformation process; outcome refers to the long-term impact of the output on the external environment(Lettieri & Masella, 2009). Based on the three above elements, three performance dimensions can be identified, namely effectiveness, efficiency and impact (Azzone, 2008). Effectiveness refers to the output characteristics, both quantitatively and qualitatively; efficiency refers to the ratio between output and input; impact is a measure of the outcome and it refers to the long-term effects of the output on the external context.

Interaction with research and administrative personnel was useful in recognizing the importance of the aforementioned dimensions. The quality of the output, the impact of the output on the society and the amount of resources required for generating the output emerged as crucial aspects for successfully manage the research centre. However, two further aspects were highlighted as central and they were consequently added to the traditional model: risk and network. The risk is associated with the uncertainty that characterizes the research activity. It is widely acknowledged that the context in which research institutes operate is characterized by continuous changes and high variability (Leitner & Warden, 2004). When discussing with the administrative and the research director, a question continuously emerged was the following: do we have enough resources, in terms of quantity and quality, in order to deal with the unpredictability of the events, such as a change in technology or a budget reduction? The importance of posing the attention to the quantity and quality of resources to deal with uncertainty, led us to complement the traditional model with the risk dimension. The network dimension is specifically related to the research activity. The heads of research units underlined several times the importance of working collaboratively in order to achieve results. Publications as well as projects or patens are rarely the result of a single researcher; rather, they derive from the joint working of more teams, belonging to the same department, but also to different departments or different research institutions. This reason justifies the choice of adding a further dimension to the model, the network, in order to capture the ability of working collaboratively and output of this collaboration.

The final model we obtained (Figure 2) is characterized by five dimensions, suggesting that the holistic management of a public research centre requires to consider the quantity and the quality of the output (effectiveness), the impact of the output on the society (impact), the ability in transforming input into output (efficiency), the quantity and the quality of the available resources (risk) and the ability and effects of working collaboratively (network). Following, each dimension will be discussed separately, posing the attention on the different relative importance given to stakeholders.

Figure 2: The proposed PMS model



The performance dimensions

Effectiveness

The effectiveness dimension allows to evaluate the output of the R&D activities defining the level of achievement of research objectives (Garcia-Valderrama and Mulero-Valdigorri, 2005). This aspect is related to a key issue that is what is the output of a research centre and how to measure it (Steiner and Nixon, 1997). In the case at hand, the output is represented by publications, funded projects, patents and technology transfer activities. Publications and projects were the 'immediate answer' when the informants were asked about the output of the research centre. This answer is in line with extant studies on research institute that recognized that publication, books and reports represent the explicit transfer of knowledge of research bodies (e.g. Coccia, 2001b). On the other hand, patents and technology transfer activities emerged in a more 'fragmented' way. Some scientific directors and researchers were fully aware of the relevance of these activities, as emerges from the following quotation:

> "Technology transfer is a key pillar in the mission of our institution, otherwise, what are we here for?" (Head of RU 8).

Whilst in the other case, patenting was seen somehow as a secondary activity that can be explained considering that the institute was at that time measuring outputs in terms of number of scientific publications and funding obtained through competitive projects. The Head of the Technology Transfer Office pointed out:

> "Technology Transfer activity is a green field. It needs to be organized and then evaluated because in the early years of the research centre, the attention has been attracted by scientific publications only. Yet we are growing and we have now a portfolio of 68 patents and several commercial projects. They need to be monitored and managed" (Head of Technology Transfer Office)

Based on these considerations, seven KPIs were defined to measure the research centre effectiveness: four of them aim to evaluate the quantity of the output and the other three the quality (see Table 5 for the details of the KPIs).

It is interesting to highlight that there was a polarization in the perceived usefulness of different aspects of effectiveness depending on the personnel qualification. The administrative personnel and the executive committee were mainly interested in the quantity of the output generated in terms of 'how much money', 'how much patents', 'how much publications' (several informants). They considered these KPIs particularly useful to support external accountability; in fact they have been included in the annual report and have been published on the website of the research institute. Instead, the scientific personnel considered these measures too 'generic' and posed particular attention to the quality of the output of research activities, highlighting the importance to account for 'good publications', 'impact on the scientific community' and 'participation in breakthrough innovation projects' (several informants). From this perspective, the Impact Factor (IF) and Citation Index (CI) distribution were evaluated particularly useful to support motivation and decision making processes of research units. Finally, the scientific director underlined the importance of the integration of the two types of indicators, for a decision making purpose, to have an overall idea of the productivity of each RU. At the same time, he also recognized the limitations of these figures: the impossibility to compare them between RUs because their average value varies widely from one research area to another one.

Efficiency

The efficiency dimension evaluates the amount of resources used to generate the output, (i.e. publications, funded projects, patents, and technology transfer activities). It represents a relevant aspect in publicly funded services as governments are interested in receiving feedback on how public resources are used (Coccia 2001a; Moreno & Tadepalli, 2002; Lettieri, Masella & Nocco, 2009).

The diversity of the output of research centres requires to define different measures in order to assess the value of the resources to generate a unit of the output, either a publication, a patent or a financed project, leading to the identification of four KPIs (see Table 2).

The relative importance of these measures was different according to the stakeholder and its organizational position. The administrative director and the scientific director were the stakeholders most interested in efficiency indicators. They strongly underlined the need to keep under control how many resources the centre employs for carrying out research activities and the time spent doing this.

> "Monitoring costs is a key issue for us. We have to keep out costs under control and we need to be able to show how much efficient we are. […] From time to time, someone stands up and claim they we spend too much. We need to be able to prove that it is not true, we spend money, but we produce more" (Administrative director)

In order to satisfy his requirements, a synthetic efficiency measure to evaluate the overall ability of the administrative staff in supporting research activities was included: the ratio between the external budget and the number of FTE (Full Time Equivalent). The fundamental resource of the institute is represented by people, and this measure gives the possibility to evaluate the cost for managing a unit of personnel. The executive committee considered efficiency relevant too, though from a different perspective. The committee poses particular attention on two specific performance indicators, cost of a scientific publication and incidence of the external budget on the internal budget, both considered useful in supporting the external accountability. These numbers are already included in the annual report of the institute and they are explicitly depicted with the purpose to increase the awareness of external stakeholders about the research activity. The heads of the research units and the researchers, on the other hand, downplayed the importance of efficiency measures, following the idea that 'research is what counts' no matter how much it costs. Some of them even argued that measuring the 'cost per output' is not relevant for the management of a department, 'what they need to know is the budget'.

Impact

The impact dimension measures the outcome, i.e. the effects of the output of the research activity on the external environment. This aspect has been highlighted several times as crucial for the research centre. It represents the mission of the institute:

> "The Foundation has the scope to promote the technological development of the country and the technological education, in line with the scientific and technological national policies with the final aim to support the development of the productive Italian system" (Foundation Statute, 2012: 3).

The importance of measuring the outcome is closely connected with the need of being externally accountable, providing information to external stakeholders on how public money is used. The administrative director was clear on this point since the kick-off meeting of the project:

> "The philanthropic mission of our Institute is to generate know how and employment for our country. We are receiving public money and we have, not only the duty to account about how we are using public funding, but also we want to demonstrate that we are using this money to support the technological development of our country"(Administrative Director).

However, the selection of the most appropriate impact indicator required to balance the trade-off between the relevance of measuring the outcome and the cost for collecting these data. In fact, the measurement of this aspect is far from being straightforward given the intangibility of the output and the existence of external factors that makes it difficult to isolate the impact of research activities on the territorial environment. The KPIs finally selected were related to cash flows from patents, licenses and technology transfer (see Table 2). They are a proxy of the outcome because they give the possibility to account for the first order effect of a research activity, which are leading indicators of second orders effect about impacts on the environment.

The scientific and the administrative directors of the centre were particularly keen on starting measuring these aspects, whilst part of the administrative and research staff were somehow worried. The motivation at the basis of this situation was that at present that the cash flows generated by these activities are still modest and they feared that numbers could lead to wrong interpretations. Directors of research units did not perceived the importance of measuring impact, being more attracted by KPIs about the quantity and the quality of the publications.

> “Patents, for my department, represent a cost. They do not generate income; this information can be useful at the overall institute level. It takes some years for a patent before gene rating money; hence, it is not relevant to manage my activity. I’ve already seen the result of my research!” (Head of SF3)

Risk

The risk dimension is associated with the need to deal with the uncertainty and the variability of the research context, as stated by the scientific director:

> “Research trends change every year. On the basis of what happens outside, I need to reconfigure the research activity inside here. The organizational structure should be flexible and follow these changes accordingly. I need to be able to modify timely the structure of scientific units; acquire new competencies, understand what happens if I close a department and open a new one” (Scientific Director).

In particular, the emphasis given to flexibility and adaptability drove the choice of posing particular attention to how the centre can monitor its resources in order to ensure its ability to respond to unexpected events. In highly uncertain contexts, resources and the capability to reconfigure them are conceived as the basic mean through which an organization can face risks (Arena, Arnaboldi & Azzone, 2010b; Arena, Arnaboldi & Azzone, 2011; Lettieri, 2009; Lettieri, Masella & Radaelli, 2009). Hence, monitoring the ‘state of resources’ can provide relevant information about how the organization could face a transformation. Obviously, this also poses the problem of identifying which are the key resources, i.e. which are the resources critical for the success of research institute. In the case at hand, four main elements were identified: human resources, financial resources, scientific equipment and reputation; and seven indicators were defined to monitor these elements (see Table 5).

Once again, a different level of awareness and sensitivity of the stakeholders towards different issues became visible. In particular, the scientific director was very attentive to read the implications of any variation in different types of resources, going beyond numbers.

> […]“I want to monitor the age of scientific personnel because it provides very useful information to me. I want a young research centre with a high turnover and many PhD: by monitoring the age of the staff I can account for this aspect avoiding the risk of increasing the average age” […]“The trend of PhD students for me is a signal. If their number falls down, it is an alarm bell to me. First, they are a resource, they are our primary row material. Second, if they stop coming here, they going somewhere else. This means that other institutions are more attractive than us. Why? I mean, it’s something to keep under control” (Scientific Director).

On the other hand, the administrative director and the executive committee appeared more focused on financial resources and reputation (in particular in relationship to the public opinion) that was sees as a considerable source of risk.

> “We are on the newspaper almost every day. Public opinion poses particular attention on the way in which we are employing public money. If we do not justify how the public funding is used, we are immediately accused of wasting financial resources that could be used for doing something else” (Administrative Director).

Finally, directors of RUs showed more interest for the scientific reputation as it gives the possibility to understand how individual researchers, not only the centre as a whole, are known and considered in a specific field of research.

Network

The network dimension refers to the ability of the research personnel working together with researchers from internal teams or from other external institutes. This aspect finds a rationale in the organizational changes that are affecting the research activities. Collaboration is nowadays considered an essential requirement (Saez et al., 2002) to survive in a research landscape characterized by inter-disciplinary activities (National Academies, 2005). The network dimension accounts for this collaborative behaviour considering the structure of relationships between actors, the quantity and the quality of the joint output and the cost of collaboration. This aspect is emerging in the public sector literature as a relevant performance dimension to evaluate collaboration (e.g. Provan & Milward, 2001), while it has received less attention in the R&D field (e.g. Allen at al., 2007). Three KPIs were included in the set of indicators, focusing on the quantity and the quality of joint publications (see Table 2). Even though collaborative activities relate also to patents and research projects, no network KPIs were associated with these typology of output. With respect to patents, the decision was to not include indicators because of the limited amount of patents compared with publications. Considering projects, measurement difficulties were identified, mainly related to the complexity of accounting joint internal projects. The main concern associated with this aspect was the following:

> "The majority of financed projects is carried out in a collaborative way; it is therefore not useful to know the level of collaborations as it is by definition that we are collaborating. This is not true for internal research projects, but they are usually carried out by the single research team". (Head of RC 3).

Again, the importance of evaluating the network dimension was different depending on the type of stakeholder. Collaborative activities emerged several times during interviews and meeting with the scientific personnel and the scientific director.

> "We are working several times with people from other research centres. This is associated with a greater effort in terms of coordination but better results because of different competences (Senior scientist 1)."

On the contrary, they were never mentioned by the administrative staff and the executive board.

The final set of indicators

Table 5 outlines the final set of indicators related to the five performance dimensions previously introduced and highlights the priorities assigned to each indicator by different stakeholders.

Table 5: The set of indicators and stakeholders priorities

Dimension	KPI	Stakeholders			
		Admin. Director	Scientific Director	Executive committee	Head of RU
Effectiveness	Number of scientific publications	X	X	X	
	Number of patents	X	X	X	
	Number of technology transfer activities	X	X	X	
	Stock of competitive projects		X	X	X
	IF distribution		X		X
	CI distribution		X		X
	Success rate of competitive projects		X	X	
Outcome	Revenue generated by patents, licenses and spin-off	X	X	X	
	Revenue generated by technology transfer activities	X	X	X	
Efficiency	Cost of a scientific publication	X		X	
	Cost to manage and maintain a patent	X	X		
	External budget/Internal budget	X	X	X	
	Internal budget/FTE	X			
Risk	Scientific reputation	X	X	X	X
	Press coverage	X	X	X	
	Capex and Opex	X			
	Employees (category, nationality, age, degree, genre)		X	X	
	Turnover		X	X	
	Organizational climate		X		X
	Saturation of equipment		X		X
Network	Number of joint publications		X		X
	IF of joint publications		X		X
	CI of joint publications		X		X

During the second phase of the action research cycle, the cost and validity of the proposed set of KPIs was verified, providing practical guidelines to the research centre for the implementation of these measures. Results of this phase vary according with the performance dimension.

KPIs related to effectiveness are diversified in terms of cost of measures. Most of them can be easily calculated because they base on data that are already collected for different purposes. The most relevant exceptions are the Impact factor and Citation index distribution. These indicators, though considered very important for the assessment of the quality of the research by the scientific director, require ad hoc data collection and further elaboration in order to 'clean' data. Effectiveness indicators are particularly relevant to have an overall idea of how the centre is performing and to assess the performances of each RU with respect to its research areas; however, they require some cautions in relationship to data interpretation, since different RUs cannot be easily compared with each other based on these numbers (e.g. bibliometric indicators change significantly in different research fields).

KPIs in the outcome dimension aim to provide a proxy of the impact of the research activity on the society. Data about cash flows are already monitored for accounting purposes. However, they provide only a partial information about the impact of the research activity on the society. Hence, it could be interesting to complement them through qualitative information to have a more comprehensive idea of research outcomes.

KPIs related to the efficiency can be quite easily calculated because the institute already monitors cost information very precisely. However, the interpretation of these data can be controversial. In particular, this is the case of the cost per scientific publication that answer to the need of external accountability. Similar to effectiveness indicators, it varies significantly across different research units depending on the specific research field (equipment, materials, and other research instruments significantly vary in different research areas, resulting in different costs per publication).

KPIs concerning the risk dimension are characterized by some differences in term of measurement costs. Capex, opex, turnover and data about employees can be determined easily, instead this is not the case for indicators about the reputation, saturation of key equipment and the organizational climate that entail ad hoc data collection. Reputation and saturation of key equipment capture two aspects that are particularly relevant for the research centre, but, at present, they cannot be calculated automatically, and the computation ask a great effort to collect data and to elaborate them; in the next future, these indicators could benefit from the exploitation of some supporting tools to collect data routinely. The organizational climate, on the other hand, is assessed through a survey yearly and it suffers from the limitations that are typical of similar approaches (e.g. risk of bias, limited timeliness).

Finally, KPIs in the network dimension exploit the same data base of those related to effectiveness, and share their strengths and weaknesses. In addition, they provide an overall picture of the extent to which researchers of different RUs collaborate, without entering into details of the contribution of different parts to the research outputs.

4 CONCLUSION

This paper aimed at constructing a performance measurement system (PMS) for a public research centre characterized by the presence of a diverse set of stakeholders with multiple objectives, ranging from making decisions, motivating researchers to demonstrating external accountability. The PMS has been developed through action research with respect to a specific context, an Italian technological research centre, where the researchers recursively interacted with different stakeholders in the construction of the PMS. Based on the state of the art literature and data collected from the interviews, a multidimensional framework for measuring R&D performance was proposed and a set of KPIs was developed. The traditional process-oriented model (Pollanen, 2005) that encompasses the performance dimensions of effectiveness, efficiency and impact, was complemented with two further dimensions of risk and network. The former aims to monitor the uncertainty that characterizes the research activity, and the latter allows to capture the ability of working collaboratively. The introduction of these two dimensions moves from the idea that the PMS should be aligned with the characteristics of the organizations in which it is used and the trends of development they should deal with (e.g. Chiesa et al., 2009).The set of KPIs puts together the information needs of different stakeholders that showed a definite interest in relationship to a certain subset of measures, often disregarding the others. The integration of different information needs in a comprehensive set of indicators aimed at providing a holistic picture of the centre performances to all the relevant actors, raising their attention on the existence of potential trade-offs between different measures.

This study contributes to the extant literature in two different ways. First, models, frameworks and methodologies for measuring R&D performances have mostly focused at the firm level, with an economic or strategic focus (Secundo et al., 2010). We deployed them in the context of a public research institute, where attention of researchers, so far, concentrated on the one specific stakeholder – the government – that is mainly interested in an overall assessment of research centres' performances in relationship to funding allocation. Second, we tried and integrated the concepts for performance measurement and performance management of interdisciplinary collaborative research, which depicts new challenges for promoters and science managers in the research environment of the twenty-first century (Agostino & Arnaboldi, 2012; Arena & Azzone, 2005; Arnaboldi & Azzone, 2010).

Since the research was conducted in a specific organization, the possibility of generalizing the results to similar institutions is a key issue. Hence, it is important to distinguish between what is general in scope and what is case-specific. First, the multi-dimensional framework proposed aims to be general in scope. The use of the process oriented model as a starting point and the integration of the two dimensions of risk and network aim to make the PMS model more coherent with the pressures that public research organizations are currently experiencing in different countries. Focus on efficiency and effectiveness, call for interdisciplinary research and growing uncertainty are key challenges for these institutions. Moreover, risk and network represent two trends of development in relationship to performance measurement in different types of organizations (e.g. Provan and Milward, 2001), though, in most of cases these performances are not formally integrated in the PMS (e.g. Arena et al., 2011). This paper represents a possible way to explicitly integrate these aspects in the PMS, opening the path to future research to further adapt the proposed model to different contexts. The second result of general validity is the approach followed to develop the set of KPIs. The choice of the KPIs was guided by the priorities of different stakeholders. Their requirements and the purpose of use in relationship to different information were mapped and cross-checked in order to build a set of indicators that would be comprehensive and transversal to the whole organization. The set of indicators, on the other hand, is case specific and reflects the characteristics of the research centre under investigation, even though it could provide source of inspiration for similar organizations.

Finally we address the limitations of this work. The data were collected through a qualitative and collaborative methodology, action research; hence the results suffer from the limitations that are typical of this research methodology. In particular, action research is situational, hence, many of the relationships between people, events, and things are a function of the situation as relevant actors currently define it and they change as the definition of the situation changes (Susman & Evered, 1978). Accordingly, while the collaboration between the researcher and the institute staff led to the identification of the KPIs, it may have also resulted in a degree of bias. However, this methodology gave us the possibility of having lively, detailed and involved discussions with members of the organizations. Our ideas about performance dimensions and KPIs were critically challenged in order to satisfy their specific requirements. Moreover, the active participation of users and the integration of their different informational requirement contributed to reducing resistance to the project and promoting the development of the PMS. An important field of future research remains the applicability of the proposed model and methodology to other public research organizations in order to verify its generalizability in different institutions operating in different countries.

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