Scientometrics (2015) 102:151–168
DOI 10.1007/s11192-014-1427-z

The impact of hybrid public and market-oriented financing mechanisms on the scientific portfolio and performances of public research labs: a scientometric analysis

Mario Coccia · Greta Falavigna · Alessandro Manello

Received: 5 December 2013 / Published online: 23 September 2014

Abstract The scientific problem of this study is the analysis of the portfolio of outputs by public research labs in the presence of hybrid funding scheme based on public and market-oriented financing mechanisms. Research institutes are considered Decision Making Units, which produce two different kinds of scientific outputs using inputs. We consider some scientific outputs with more international visibility (High Visibility Outputs-HVOs) than others called Low Visibility Outputs (LVOs). We confront this problem by a scientometric approach applying models of the Directional Output Distance Function, which endeavours to measure and analyze the effects of hybrid financing of public research labs in terms of potential loss in high quality scientific outputs, in particular when the share of market-oriented funds is beyond a specific threshold. Results, considering R&D organizations of "hard sciences", seem to show that a hybrid financing scheme, too market-oriented for supporting operation (and survival) of research labs, tends to affect scientific output portfolio by lowering scientific performances and HVOs. The study here also proposes a preliminary analysis of the optimal level of market financing in relation to total financial resources for a fruitful co-existence of market and public funding scheme to maximize the

M. Coccia
National Council of Research of Italy, CNR-Ceris, via Real Collegio 30, 10024 Moncalieri, To, Italy

M. Coccia
RAND Corporation Washington Office, RAND Corporation, 1200 South Hayes Street, Arlington, VA, USA

M. Coccia (✉)
Maastricht Economic and Social Research Institute on Innovation and Technology, United Nations University, UNU-MERIT, Keizer Karelplein 19, 6211, TC, Maastricht, Netherlands
e-mail: m.coccia@ceris.cnr.it

G. Falavigna · A. Manello
Institute for Economic Research on Firms and Growth (CNR-Ceris), National Council of Research of Italy, Via Real Collegio 30, 10024 Moncalieri, To, Italy
e-mail: g.falavigna@ceris.cnr.it

A. Manello
e-mail: a.manello@ceris.cnr.it

scientific output (publications) of R&D labs. The findings show main differences across scientific departments and some critical weaknesses points and threats by public research labs for production of scientific outputs.

Keywords Public research labs · R&D organizations · Publications · Market funding · Strategic change · Scientific Portfolio

Introduction and the problem

The public research sector includes academic institutions, Public Research Bodies (PRBs) and other subjects that produce scientific research, a public good, which unless properly financed through public funds, is doomed to market failure. In general, the research labs do not maximize profit, but rather their scientific reputation and international prestige, focusing on high quality scientific outputs, such as international publications and patents (Coccia 2008; Llerena et al. 2003; Crow and Bozeman 1998; Mitsutaka et al. 2010, etc.).

An interesting and relatively new problem (p*) is *how* the portfolio of scientific outputs by public research labs changes in the presence of shrinking public research lab budgets by governments.

In fact, current financial and economic crisis, meanly across European countries, is generating continuous cuts to public research lab budgets such that these institutions are forced to attract market funds by supplying technological services and consulting activities to support their operation, scientific activity and survival (Stephan 2012; Coccia 2012). This organizational behaviour of research labs is important to take advantage of important market opportunities and to cope with consequential environmental threats due to low public funding by governments (Coccia 2012). The strategic change[1] of public research labs affects the production of scientific research and as a consequence the portfolio of scientific outputs. Van Looy et al. (2004, p. 425, original emphasis) argue that the increase of entrepreneurial activity within academia has raised concerns such that the research orientation of universities can be 'contaminated' by the application-oriented needs of industry (cf. also Nagy et al. 2014). These scholars show that the engagement in entrepreneurial activities of universities and PRBs may increase publication outputs, without affecting the nature of the publications (cf. Czarnitzki et al. 2011; Czarnitzki and Kraft 2012; Czarnitzki and Thorwarth 2012; Czarnitzki and Toole 2010).

Public management, as a consequence, tends to design strategies based on a fruitful co-existence of public and market-oriented funding mechanisms also to support scientific performances of research bodies (Coccia and Rolfo 2008, 2009). Considering this hybrid approach of funding mechanisms by public research labs that combine public and market-oriented financial resources, the fundamental question (q*) is what combination of funding within PRBs sustains the scientific portfolio of R&D organization by higher outputs (e.g. publication on leading journals).

This study confronts the problem (p*), by developing a scientometric analysis to measure and assess the vital impact of increasing share of external funding in terms of potential reduction of scientific performances and loss of high quality scientific outputs by Public Research Bodies (PRBs) in turbulent and fast-changing markets (cf. Coccia and Cadario,

[1] "*Strategic change* involves an attempt to change current modes of cognition and action to enable the organization to take advantage of important opportunities or to cope with consequential environmental threats" (Gioia and Chittipeddi 1991, p. 433).

2014). In particular, the purpose of this study is to design a model of R&D performance evaluation that considers two typologies of outputs jointly produced in a PRB: High Visibility Scientific Outputs (HVOs), characterized by international relevance and novelty and Low Visibility Scientific Outputs (LVOs), focused more on applied activities, technological services and consulting activities. This study also endeavors to answer the research question (q*) of pinpointing the optimal combination between market-oriented funding and total financial resources of research labs that maximizes the scientific publications. The empirical evidence is based on a representative case study: the Italian National Research Council, the larger research institution in Italy. The scientometric analysis of this case study is interesting because it considers a research body and a context of shrinking public research lab budgets similar to several European countries.

Theoretical background and related works

Current PRBs have a strategic change based on the attraction of market funds by offering their technical skills and technological services to external institutions (Coccia 2005, 2008, 2012; Coccia and Rolfo 2007, 2008, 2010, 2013). This new organizational behaviour, mainly *market-oriented*, generates reports and other low visibility scientific outputs (Carayol and Matt 2004). Groot and García-Valderrama (2006) show results from 169 Dutch research groups, considering the origin of their funds, and find that the amount of national funding is positively related to academic quality, whereas the gains from external research commitments are negatively related to academic quality (cf. Hicks 2012). The scientific outputs have a different quality and visibility for academic community, hence the apt evaluation of research performances by labs should be based on a methodology that considers types of scientific outputs and their production associated to combinations of public and market-oriented funding mechanisms. Social scientists usually estimate cost functions by Data Envelopment Analysis (*DEA*) that is a suitable managerial tool to compare performances of generic Decision Making Units (Athanassopoulos and Shale 1997; Abramo et al. 2011; Kao and Hung 2008; Anderson et al. 2007).

An alternative methodology to *DEA* is the use of stochastic cost frontiers (Coelli et al. 1989) but this technique has the disadvantage of needing assumptions on the functional form of the best practice frontier and underlying production function. However, this approach has not widely used in the managerial literature. *DEA* methodology represents a more proper instrument for assessing technical efficiency of scientists for its flexibility and the small number of assumptions needed. The current debate concerns the selection of variables for the production model because results can change according to the specific choice of inputs and outputs. For example, Sarrico et al. (2009) use a linear mixed-effect model with random effects at university level to measure the productivity of Portuguese public universities, taking into account their field specialization. Scientific productivity is measured considering articles published in journals included within *Journal Citation Reports*® (JCR) by Thomson Reuters. Another approach is proposed by Abbott and Doucouliagos (2003) that measure the productivity of Australian universities by distinguishing between teaching and research activity, but some main problems remain unsolved such as agreeing on how to evaluate research outputs. The study here proposes a partial solution to this problem by designing a model that consider both HVOs and LVOs, following Falavigna and Manello (2014), which have applyed an approach to analyze the different impact of funding schemes on scientific productivity and production of research labs over time.

Study design: method and materials

Modelling scientific efficiency with high and low visibility scientific outputs

A DEA frontier has been built using Directional Distance Function (DDF) a concept that allows the introduction of qualitatively different outputs. This flexible definition of distance is proposed by Chambers et al. (1996) and it encompasses input and output distance function in a standard DEA formulation. The theoretical properties of DDF are analyzed by Chambers et al. (1998), Färe and Grosskopf (2000) and its strengthen relies in the possibility of modifying the direction in which looking for the efficient counterpart of each DMUs (Decisional Making Units). This approach allows to change the concept of productivity without modifying technology representation via data transformation. In particular, the modelling of the scientific production function by public research institutes in our model can be based on three types of variables:

- *Inputs* (e.g. funds, human resources, etc.);
- *High Visibility scientific Outputs (called HVOs)* such as articles in the JCR, refereed articles, books; These outputs are based mainly on theoretical research and are in general financed by public funds;
- *Low Visibility scientific Outputs (LVOs)* such as internal and external reports that have low international impact. These outputs are funded by specific market (external) projects of applied research.

As current public funds are not sufficient to support scientific research of public research labs and to cover ordinary costs of the structure (such as computer maintenance, telephone, electricity, journal subscriptions, data access and so on), Public research labs need to attract market funds to support scientific research producing both LVOs and HVOs. We start from a classical framework, where a vector of input $x = (x_1, \ldots, x_N) \in R_+^N$ is implied to produce a vector of scientifically desirable outputs $y = (y_1, \ldots, y_M) \in R_+^M$, named HVOs, and a vector of less desirable under the purely scientific point of view, outputs $b = (b_1, \ldots, b_J) \in R_+^J$ named LVOs. The output set $P(x)$ consists of *HVOs* and *LVOs* combinations that can be produced using an input vector x; it could be written as:

$$P(x) = \{(y, b) : x \quad \text{can produce}(y, b)\}, x \in R_+^N \tag{1}$$

Following Färe et al. (2007), the standard axioms, coming from standard production theory, are satisfied by the scientific production function in presence of LVOs: *Inactivity, compactness and free disposability of inputs.*

Moreover, the specific characteristics of LVOs are translated in two additional axioms, which are added to the classical production framework to reshape the production set.

1. *Null jointness*. If two categories of outputs are produced, LVOs cannot be reduced to zero because they strictly are linked to external funds and generated by specific projects that also support HVOs and operations of public research lab. In notation:

$$\forall y \in Y, \forall b \in B, b = 0 \Rightarrow y = 0$$

2. *Weak disposability of outputs*. As the scientific production of HVOs and LVOs is interlinked within the organization system of public research labs, a reduction of LVOs can also imply a reduction of HVOs with a reduction of general scientific production when inputs are maintained unchanged. In particular, if a research lab

decides to reduce *LVO*s, the flow of external fund also decreases because LVOs are the natural outcome of external research projects. This reduction of resources will immediately cause a proportional contraction in HVOs because government funds are not enough to cover operational costs. In analytic notation, let $P(X)$ be the production possibility set and $0 \leq \alpha \leq 1$:

$$(x, y, b) \in P(x) \Rightarrow (x, \alpha y, \alpha b) \in P(x)$$

The standard assumption of *free disposability* in outputs continues to hold only for the subset of *HVOs, then a reduction of HVOs* maintaining inputs and *LVOs* fixed, is always possible without costs.

The Directional Output Distance Function (DODF), defined on $P(x)$, gives the maximum feasible proportional contraction of LVOs and expansion of HVOs (cf. Chambers et al. 1996). DODF takes a value equal to 0 for efficient Decision Making Units (DMUs), which are on the frontier and increase with inefficiency, analytically:

$$\vec{D}_0^W(x, y, b; g_y, g_b) = max\{\beta : (y, b) + (\beta g_y, \beta g_b) \in P(x)\} \tag{2}$$

where $g = (g_y, g_b)$ is the directional vector and $P(x)$ is the production possibility set estimated via linear programming, after fixing a particular directional vector that condenses the multiple objectives of labs. Assuming that institutes are not worried about reducing LVOs, but they want to increase HVOs for boosting their reputation. Therefore, we assume a directional vector $g = (y, 0)$ that implies a maximization of HVOs. The value of DODF can be estimated by linear programming:

$$\begin{aligned} \vec{D}_0^W(x^k, y^k, b^k; y^k) &= \max\beta \\ s.t. \quad x^k &\geq Xz \\ (y^k + \beta y^k) &\leq Yz \\ b^k &= Bz \\ z &\in R_+^k \end{aligned} \tag{3}$$

The directional output distance function re-scales the observed output vector (*y, b*) on the frontier, following the g direction that is $(y, 0)$ in our case. When $\vec{D}_0^W(x^k, y^k, b^k; y^k) = 0$ institute k is on the frontier or, in other words, it does not exist another institute—or a linear combination of efficient labs—able to produce a larger amount of HVOs, fixed inputs and *LVOs*. A value of $\vec{D}_0^W(x^k, y^k, b^k; y^k)$ greater than zero gives the level of inefficiency and in particular the technically feasible expansion of HVOs. Two additional standard DEA models are estimated, as a matter of comparison, including LVOs and not including these outputs.

The opportunity costs hybrid funding scheme

The funding scarcity prevents the free distribution of efforts in the scientific production and *LVOs*, according to external funding requirements, to support operation of public research labs and, as a consequence, also *HVOs*. This constraint modifies the shape of the best-practice frontier through weak disposability in the DDF contexts. If we relax the assumption of *weak disposability*, the output set and the piece-wise linear frontier can be estimated as if the hybrid funding scheme disappeared (Färe et al. 1989), and all funds are from the government. Technically, linear problems remain, similar to Eq (3), but the last equality is replaced by an inequality with an unchanged directional vector:

$$\begin{aligned} \vec{D}_0^F(x^k, y^k, b^k; y^k) &= \max\beta \\ s.\ t. \qquad x^k &\geq Xz \\ (y^k + \beta y^k) &\leq Yz \\ b^k &\leq Bz \\ z &\in R_+^k \end{aligned} \tag{4}$$

This means that it is possible to decrease LVOs without costs, i.e. without a subsequent contraction of financial resources. In other words, this is equivalent to assume that self-financing constraints do not exist anymore, and by comparing these two sets of results it is possible to create a proxy of scientific output loss due to the coexistence of public and market funds. Picazo-Tadeo and Prior (2009) show that the opportunity cost (OC) in terms of desirable outputs can be derived as:

$$\mathrm{OC} = \vec{D}_0^F(x^k, y^k, b^k; y^k) - \vec{D}_0^W(x^k, y^k, b^k; y^k) \tag{5}$$

This index can only give a partial proxy of the opportunity cost imposed on institutes, which have to balance LVOs and HVOs for a scientific and financial organizational equilibrium. The only effect that can be measured, in case of weak disposability, is the visible difference from the actual best practice frontier to a hypothetical free disposable one, which derives from all previous choices taken under financial constraints.

Data and sources of the case study

The model of previous section is tested on the Italian national research council (CNR), which is an interesting case study due to its relevance, in terms of size (it is the largest Italian research institution) and huge public fund cuts by governments during last years (Coccia and Rolfo 2002, 2008; Coccia 2012; Tuzi 2005). In addition, this structure is similar to other European research institutions (such as CNRS in France, CSIC in Spain, Max Planck in Germany, etc.), such that its organizational behaviour can provide main tendencies of strategic change in the European research sector. We decide to focus on institutes operating in natural sciences and engineering, called "hard science", which are a rather homogenous sample, over 2004 and 2007 year. In particular, we analyse data of 75 public research labs concerning nine departments, which are:

Departments	Main research activities
Earth and environment	Earth system; global change; quality of environmental systems; sustainability of land and water systems; natural and anthropogenic risks; earth observation, pollution control and ecological restoration; environment and health
Agribusiness and food	Genomics in agriculture; sustainable agriculture; food

Departments	Main research activities
Medicine	Molecular and clinical imaging, bioinformatics and high-throughput approaches for genetic and pharmacologic screening, bioinformatics and regenerative medicine
Life sciences	Proteomics and bioinformatics; genomic medicine (including clinical genetics research); population genetics, genetic epidemiology and complex diseases
Molecular design	Design and medicals development; polymeric systems; sustainable chemistry; functional nanosystems
Materials and devices	advances in: atomic and molecular condensed states; technological use of matter; synergy among physics, chemistry, biology and engineering in the area of nanomaterials
Engineering and production systems	Electronics, magnetic materials, automations, ceramic materials, building technologies; acoustics
Information and communication technology (ICT)	Telecommunications; data mining, semantic web, grid and high performance computing, simulation and complex systems, information security
Energy and transport	Clean energy generation from fossil fuels; rational use of energy in transport distributed energy generation; participation in national and international fusion projects; nanotechnologies and physical metallurgy for energy and transport components; sustainable mobility

The main inputs of public research institutes, according to the CNR balance sheet, are:

- Researchers
- Administrative staff
- Government funds (a proxy of capital stock)[2]
- Market funds (resources from external subjects for specific and committed research projects)

Whereas, the outputs, from the so-called "Research output database" by CNR, are:

- Four HVOs (articles in the JCR, refereed articles not in the JCR, books and patents)
- Two LVOs linked to external projects (e.g. reports and other editorial activities)

Table 1 shows descriptive statistics for inputs and outputs over 2007 year.

Results of the scientometric analysis

Linear programs in Eqs. 3 and 4 are solved using statistics software *R* for each DMUs in the sample of institutes operating in hard science. Moreover, two additional standard DEA models have been estimated, as reference, adopting standard assumption on outputs, including or not reports among the outputs of research activities. Table 2 shows results for each scientific departments[3] because we are interested to display the potential effect of

[2] These funds are allocated considering the past distribution, but they tend to be higher in case of a large laboratory or complex machinery.

[3] Institutes were grouped in 11 departments after the 2003 restructuring of CNR. We consider 9 departments, excluding social and humanistic institutes. Note that from 2013 onwards the 9 departments in natural and engineering sciences have been aggregated in 6 macro-departments.

Table 1 Descriptive statistics of inputs and outputs by public research labs (2007 year)

Variable	Arithmetic mean	SD	Min	Max
Inputs				
Researchers	41	23	9	158
Administrative staff	26	22	4	174
Government funds (000)€	819	579	88	3,158
Market funds (000)€	2,526	5,816	25	50,828
HVOs = high visibility outputs				
Patents	1	2	0	10
Articles in the JCR	65	44	2	208
Books	11	13	0	68
Refereed articles not in the JCR	13	17	0	111
LVOs = low visibility outputs				
Reports	16	26	0	146
Other editorial activities	3	7	0	54

hybrid funding mechanisms, more and more focused on market-oriented funding, on HVOs and LVOs.

The first column shows the efficiency scores of departments estimated with DODF and weak disposability (i.e. *hybrid funding scheme,* scarcity of public funds such that the research labs need to gather market funds, which tend to generate LVOs affecting the production of HVOs). The second column reports efficiency results from DODF, relaxing weak disposability assumption that is a situation in which there are sufficient government funds such that it is not necessary for labs to gather market funds (public funding scheme). The third column shows the efficiency scores from a standard DEA model, based on HVOs as outputs, whereas the fourth column presents efficiency scores from a DEA model, where both HVOs and LVOs are considered as outputs.

Considering HVOs and LVOs, Table 2 shows that Energy and Transport, and Medicine departments have a lower scientific efficiency (lower HVOs and LVOs, fixed inputs), whereas ICT and Molecular Design Departments have a higher scientific efficiency (see column 1). If the model does not consider LVOs (column 2–3, in Table 2), inefficiency of departments in terms of scientific outputs increases, confirming managerial and economic literature. In particular, inefficiency (lower HVOs fixed input) is higher in Energy and Transport and Medicine because, in general, the institutes in these departments have larger labs and need more economic and human resources to operate. Column 4 reports inefficiency levels assuming both HVOs and LVOs in the objective function: results confirm previous analysis.

Table 3 displays the percentage of HVOs loss due to a focus of research labs on market funds that generate, more easily, LVOs (that are also necessary to the operation of labs and represent the outputs of applied research projects).

Higher weight of market fund in 2004 is by institutes operating in Agribusiness and Food, ICT, Earth and Environment departments, whereas lower results are by Life Sciences, Materials and Devices. The year 2007 confirms the results of 2004, however there is a general increase of the share of market funds by overall institutes (see Column 1 and 2 in Table 3). Moreover, Table 3, column 3, also shows that the research institutes of Life Sciences, although they do not collect so much market fund (a time consuming activity for

Table 2 Efficiency results by departments, 2007 year

Department	*D* (0, *y*) weak	*D* (0, *y*) free	DEA without LVOs	DEA HVOs + LVOs
Agribusiness and food	0.355	0.598	0.676	0.531
Energy and transport	1.353	1.497	1.770	1.266
Information and communication technologies (ICT)	0.327	0.535	0.813	0.351
Materials and devices	0.400	0.595	0.731	0.553
Medicine	1.295	1.923	1.946	1.506
Molecular design	0.333	0.494	0.586	0.465
Life sciences	0.532	0.733	0.792	0.648
Engineering and production systems	0.585	0.742	1.181	0.428
Earth and environment	0.479	1.031	1.179	0.747

HVOs high visibility scientific outputs, *LVOs* low visibility scientific outputs, *DDF* directional distance function

institutes in terms of time and administrative burden, Coccia 2009a, b), they are able to increase HVOs by 48.5 %, while Medicine by 34.2 %. These results suggest that in certain research fields, the hybrid funding scheme implies a sort of trade-off between HVOs and LVOs. However, institutes of the department Earth and Environment show that, in 2004, though they have a higher share of market funds, opportunity costs relative to the hybrid funding scheme tend to be lower. Similar organizational behaviour can be observed for departments of Material and Devices, Engineering and Production Systems. This means that, in these research fields, market funds are based on research projects closer to scientific activities of R&D units and there is a weaker *trade-off* between applied research from market projects and their activities in basic science (cf. Carayol and Matt 2004). During 2007, the further shrinking public research lab budgets imply a stronger strategic change and research labs by Earth and Environment department also pay higher cost in terms of HVOs loss. Department of Medicine shows, over 2004–2007 period, a trade-off between HVOs and market funds; this result tends to support LVOs. A general consideration is that some departments, such as Energy and Transport, Agribusiness and Food, and Life Sciences, display interesting learning processes within the organization and they show a better capability to achieve HVOs from market projects/funds (apt strategic change to new market condition and to cope with consequential environmental threats due to public fund cuts).

Finally, Table 4 focuses on 2007 period and shows the scientific loss of the specific typology of HVOs (e.g. articles in the JCR, books, etc.) considering the portfolio and research activity by each departments/institutes.

These results show that institutes are obliged to survive by collecting market funds, due to an on-going reduction of government funds and they have an opportunity cost in terms of HVOs that are not produced due to huge time spent in bureaucratic activities for this market oriented activity. Earth and Environment department shows the highest reduction of articles in JCR and not JCR journals, as well as books and this depends mainly on the average size of its labs and specific portfolio composition. The impact of the strategic change (based on hybrid funding mechanisms) by public R&D organization, in terms of loss of HVOs, tends to be higher in departments (decreasing order) of Medicine, Materials and Devices, Molecular Design, Life Sciences and ICT. The impact of shrinking public

Table 3 Share of external funds and opportunity cost of hybrid funding, 2004 and 2007

Department	Market funds on total, 2004	Market funds on total, 2007	Opportunity Cost[a] of LVOs 2004	Opportunity Cost[a] of LVOs 2007
Agribusiness and food	0.468	0.558	0.325	0.242
Energy and transport	0.363	0.451	0.232	0.143
ICT	0.460	0.519	0.249	0.207
Materials and devices	0.351	0.431	0.164	0.195
Medicine	0.440	0.538	0.342	0.629
Molecular design	0.421	0.539	0.209	0.161
Life sciences	0.280	0.493	0.485	0.201
Engineering and production systems	0.385	0.498	0.168	0.157
Earth and environment	0.483	0.571	0.135	0.552

HVOs: High visibility scientific outputs, *LVOs*: low visibility scientific output

[a] The scientific loss of HVOs due to *reduction* of government funds, and time and bureaucratic activities spent to search market financial sources

research lab budgets on HVOs seems lower in the department of Engineering and Production Systems essentially due to smaller size of labs and their scientific activities, which are close to applied research of firms and of other external subjects.

Estimating the optimal share of external funding

This study also endeavours to analyse the fruitful relationship between market-oriented funding and total resources of R&D labs that can maximize scientific output performance. The study design is based on the following research strategy. First of all, we calculate the ratio τ_i per each research lab i in the year 2007: $\tau_i = \frac{\text{market funding}}{\text{total financial resources}}$. This ratio τ_i indicates the intensity of market funding in comparison to total funding for each research lab i. In addition, we also consider the main indicator of scientific output performances by public R&D organizations: the total number of publications in referred journals (in JCR and not JCR journals, called TOTAL PUBS = y) over 2007 year (cf. Thijs and Glänzel 2008). After that, we transform the variables in logarithmic value to have normal distributions and apply correctly statistical analyses.

In order to find the optimal financial composition of the portfolio of R&D organizations, considering market oriented and public funding mechanisms, we maximize the following objective function y of total production:

$$\text{Max}[y = f(\tau)] \tag{6}$$

Considering the scatter data of our sample of institutes, the apt specification of econometric modelling is based on the following quadratic function:

$$LNy_i = \delta_i + \varphi LN\tau_i + \rho LN\tau_i^2 + u_i \quad i = 1, 2, \ldots, n\,(\text{research labs}) \tag{7}$$

Equation (7) is estimated by ordinary least squares method that provides the results of Table 5.

Table 4 Scientific loss of HVOs per type of scientific output and department (year 2007)

Department	Articles in the JCR	Articles not in the JCR	Books	Patents
Agribusiness and food	7.5	1.2	1.7	0.0
Energy and transport	7.5	0.1	0.5	0.0
ICT	9.0	1.9	1.4	0.2
Materials and devices	13.7	1.8	1.4	0.2
Medicine	18.4	2.4	1.2	0.1
Molecular design	12.2	1.3	0.6	0.3
Life sciences	12.0	0.4	0.1	0.1
Engineering and production systems	4.9	0.9	1.0	0.0
Earth and environment	28.8	9.9	10.2	0.1

These data are not weighted by the size of public research labs

Journal Citation Reports (JCR) is an annual publication by Institute for Scientific Information (ISI) by Thomson Reuters and provides citation indexing and analysis for journals and scientific outputs; articles published on *Journal Citation Reports* (JCR) have a higher impact in terms of citations

Table 5 Optimal balance of market funding regression

Dependent variable: LN Total publications 2007 per R&D labs	
Constant	3.233***
LNMRKI	−1.106**
$LNMRKI^2$	−0.280**
F (sign)	4.155 (0.02)
R^2Adj.	0.08
N	79

*** Sign. $p < 0.001$; ** sign. $p < 0.05$

Explanatory variable: LN*MRKI* = Logarithmic of (Market funding/total financial resources) in 2007 per research labs

In this context, although a small R^2, results can be good, considering other analyses and the specific research field. Figure 1 shows the fitted curve.

In particular, an optimization is performed on estimated relationship (7) (see Table 5) by nothing that this function of one (*real*) variable is a polynomial function of an order higher than the first order. Since this function is continuous and infinitely differentiable, we maximize this objective function applying the classic mathematical optimization methods.[4]

If $\theta = \mathrm{LN}y = \mathrm{LNTOTALPUBS}$ and $\sigma = LN\tau$ *(*$\tau = ratio =$ *Market–oriented financing/Total financial resources)*, the necessary condition to maximize Eq (7) is:

$$\frac{\mathrm{d}\theta}{\mathrm{d}\sigma} = -1.106 - 0.56\sigma = 0 \quad (8)$$

The first derivative equal to 0 is given by:

[4] The necessary condition for the functions of one variable in order to have the solution $x = x^*$ to be a maximum or a minimum is:

$\frac{\mathrm{d}f(x)}{\mathrm{d}x} = 0 \quad \text{for} \quad x = x^*$

In this case, x is a stationary point.

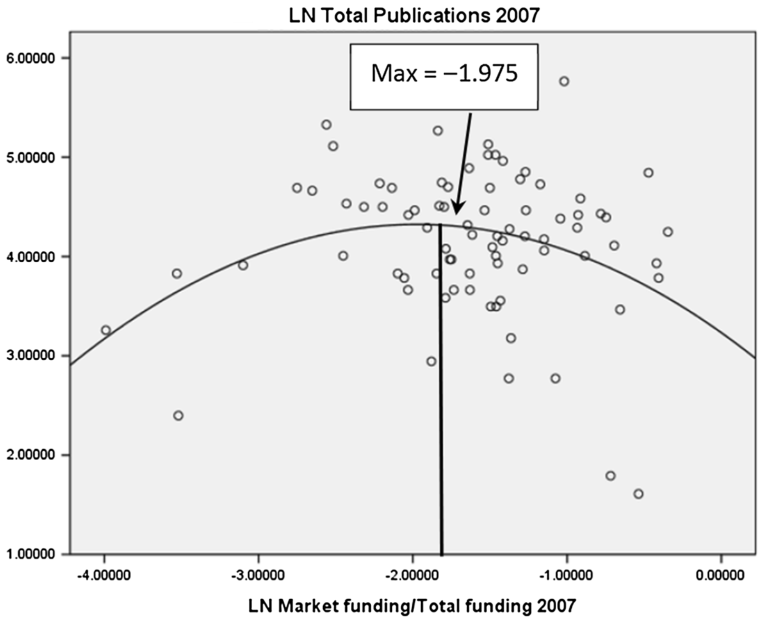

Fig. 1 LN Total publications per R&D labs on LNMRKI (where LNMRKI= Logarithmic of Market financing/total financial resources in 2007 per research labs)

$$\theta'(\sigma) = 0 \quad \sigma = -1.975; \quad \exp(\sigma) = 0.1387\,(\text{ratio} = \text{market financing}/\text{total funding}),$$

which maximizes the function (7). This value expresses the optimal balance between market-oriented financing and total funding that maximizes the scientific performance of research labs. In fact, $\theta = 4.325$, $exp(\theta) = 75.78$ = number of publications in referred journals, which is the max value of total publication associated to an optimal balance of the market funding of R&D organizations, roughly equal to 14 %, in relation to total funds. Whittington (1991), analysing control strategy of R&D organizations, such as market control, shows interesting results concerning a mixed portfolio with a balance of financing and critical thresholds. This scholar argued that many R&D laboratories have much to gain by partial adoption of market control practices (Whittington 1991, p. 43ff).

Main findings of this analytical framework are: the estimated relationship has decreasing returns of publications beyond a critical threshold of about 13.8 % of market funding/total resources (see Fig. 1). Hence, a mixed portfolio of R&D organizations based on a balanced level of market financing from 0.5 to roughly 13.8 % of total financial resources can support scientific performances (Fig. 2); beyond this threshold ($\tau > 0.1387$, i.e. value greater than 13.87 % of market-oriented funds related to total resources of R&D labs), a higher share of marker funds may trigger decreasing returns on scientific performances of R&D labs (represented by publications on leading referred journals).

Considering our sample of 79 research institutes, roughly 19 research labs (24 % of total) have a ratio of market funds to total funds within this optimal range, which tends to support scientific performances (i.e. R&D organizations are located in the increasing curve of fitted parabola with increasing returns), whereas 60 labs (76 % of total) have a higher ratio of market funds/total financial resources, with effects of decreasing returns on scientific performances (R&D labs are located in the decreasing curve of fitted parabola).

Fig. 2 Optimal composition of the portfolio of financial resources within R&D labs to maximize the scientific outputs (publications)

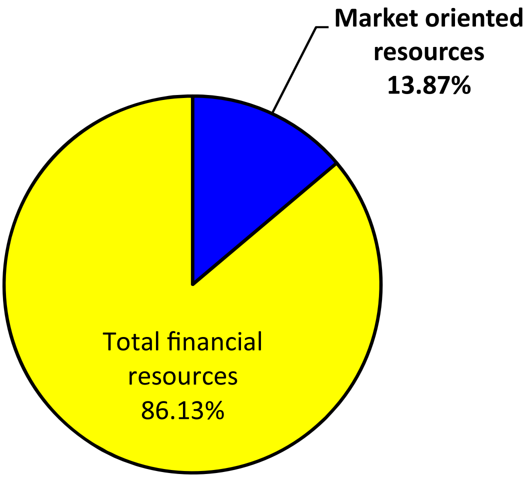

Table 6 Characteristics of research labs within and outside the optimal range delimited by the threshold of roughly 14 % (ratio: market funds/total financial resources)

Research labs nr. (%)	Under the threshold of the 13.87%		Over the threshold of the 13.87%	
	Research Labs 19 (24 %)		Research Labs 60 (76 %)	
	2004 year	2007 year	2004 year	2007 year
1. DDF (0, *y*) weak (efficiency)[a]	0.27	0.38	1.14	0.69
2. DEA HVOs + LVOs (efficiency)[a]	0.64	0.54	1.2	1
3. Number publications (referred journals)	71.89	82.63	62.8	77.18
4. Researchers (number of units)	40.37	38.63	42.92	41.63
5. Total personnel (number of units)	73.47	60.53	81.38	68.55
6. Total funding (000 Euros)	Not available	7,170.93	Not available	8,828.03
7. Public funds (000 Euros)	Not available	723.01	Not available	849.15
8. Market funds (000 Euros)	Not available	682.05	Not available	3,110.39

[a] Lower values indicate more efficiency

Table 6 displays the main characteristics of these two types of research labs considering their combination between market and total funding. Results confirm that with an optimal combination of markets funds in relation to total funding (i.e. market funding roughly <13.8 % of total resources), R&D labs have a higher efficiency, i.e. higher number of publications; in addition, these best-performer institutes tend to be of smaller size (see rows 4 and 5 of Table 6).

Discussion and concluding observations

The continuous reduction of public funds by governments leads to a new hybrid funding scheme for the research sector, where public funds and market resources coexist and influence the scientific production. This situation has changed the approach of researchers and research labs towards scientific research: they are forced to gather market funds by making more applied research activities, supplying technological services and consulting activities that seem to generate higher LVOs and lower HVOs. The portfolio of scientific output and scientific performances are changed in comparison to the past when the majority of funding was by governments (public funds).

As external market funds coming from the industrial system are very limited and essentially concern market oriented activities (i.e. fee-for-technological service in the short term period), how could research labs pursue their explicit objective of assuring good scientific research and higher scientific performances in the long run?

The paper here confronts this question by analysing the current organizational behaviour of Italian National Research Council in the presence of public fund cuts and hasty reforms that support entrepreneurial behaviour of research institutes. In particular, the institutes are increasing the portfolio of research projects from market activity as well as they are increasing bureaucratization due to higher administrative burden in managing these market activities (cf. Coccia 2001, 2004, 2009a, b). Briefly, the new organizational behaviour of Public research Labs (PRBs) tends to generate low scientific performance in terms of scientific publications measured by articles published in leading journals (called HVOs) due to public fund cuts because researchers dedicate an increasing part of their time on technological services and spend a huge amount of time for preparing grant and/or project applications, managing grants and/or projects, and so on. In fact, this strategic change affects structures and scientists that have to adapt to low public funding conditions by three strategies for selecting external funds (cf. Laudel 2006): targeting easy resources; targeting all resources and targeting appropriate sources.

Moreover, to increase the likelihood of external-market funding to support scientific activities, scientists and structures tend to apply the following organizational strategies: (a) selecting externally predetermined topics; (b) diversifying research; (c) avoiding risky research; (d) avoiding hot topics and (e) supplying all technological services and consulting activities demanded by external subjects (e.g. firms, public institutions, etc.).

The main determinants of this strategic change are financial cuts due to economic recession that is creating structural deficiencies within research organizations. This strategic change is also owing to massification of research, i.e. lower quality of the scientific research for market needs (Musselin 2007; Schuetze 2007). Furthermore, excellent scientists seem to feel the effects of forced adaptations to market funds more strongly because they have some research programs that often do not match with sponsor needs and they want to realize and are less willing to change the content of their scientific research fields (Gläser et al. 2002; Musselin 2007).

This new organizational behaviour of public research bodies based on technological services and market activities, generates the so-called academic capitalism through the commercialization of the research in a sort of entrepreneurial research units (cf. Tucker et al. 2012). As a consequence, public research units have a market-oriented organization similar to *quasi-business firms*, *with many characteristics of the business firm, except for the profit motive* (Viale and Etzkowitz 2004). This market oriented approach of research labs is compromising scientific norms and commercialization (or commoditisation, or marketization) is in deep conflict with the function and main mission of research units i.e. knowledge creation through scientific research and dissemination through publication and education (Slaughter and Leslie 1997; Coccia 2012). Goldfarb (2008) confirms that the growing share of research funded by industry has sparked concerns that researchers will sacrifice scientific activity to pursue commercial goals. In particular, researchers who maintain a relationship with sponsors have a *decrease* in publications in leading international journals. This situation implies the danger that academics' careers may be a function of market funding gathered rather than talent (e.g. within business enterprises). Moreover, Goldfarb (2008) also states that scientific merit does not necessary serve as a funding criterion for sponsor, and citations or publications are often not useful proxies for short-term social value. Moreover, Washburn (2005) offers highly critical assessment of close universities/research units-firms ties, showing the great and dangerous influences that money and corporate ties impose. She argues that business and commercial interests are negatively influencing research units and universities. Nelson (2005, p. 233) states that: "there are real dangers that, unless... [marketization of the scientific research] is halted soon, important portions of future scientific knowledge will be private property and fall outside the public domain, and that could be bad news for future progress of science and for technological progress". Other studies show positive spillover from introducing market-oriented funding mechanisms and entrepreneurial behaviour in R&D organizations (cf. Czarnitzki et al. 2011; Czarnitzki and Kraft 2012; Czarnitzki and Thorwarth 2012; Czarnitzki and Toole 2010). As a matter of fact, some countries have the lack of a long-term national research strategy and of a consistent research policy (shared by governments of different political coalitions, such as in Italy) that are generating structural deficiencies of R&D organizations and lower performances in term of HVOs. This tendency seems to be present in Italy but also in other countries such as France (Lepori and Larédo 2007), Spain (Sanz-Menéndez and Cruz-Castro 2003), Australia (Laudel 2006), Norway (Gulbrandsen and Smeby 2005), and so on.

In terms of R&D management implications, it would be better to organize Italian public research with autonomous small–medium research units specialized in basic and/or applied research, which have less bureaucratization and are more efficiency in managing current low funds for research activities. The main policy implication for Italy relies in avoiding the creation of large laboratories that have more bureaucracy, and adsorb a lot of financial resources for their running, which are more and more difficult to gather in the current European context of public spending review, competitive settings and creeping economic crisis.

Moreover, another main R&D management implications of this study is that the fruitful co-existence of market financing and public fund mechanisms within R&D organizations is linked to a level of market financing roughly <13.8 % of total resources; beyond this critical threshold (i.e. values greater than 13.8 % of market-oriented funds on total resources), there can be decreasing returns that affect scientific outputs (i.e. lower publication of HVOs) of R&D labs.

In fact, negative effects of higher market-oriented funding mechanism within public research labs may be that basic research and knowledge will be reduced in future since several public research bodies focus on applied and technological services rather than basic research. According to Laudel (2006) there is a threat that certain types of basic research will be disadvantaged everywhere. Researches whose success is difficult to predict have a low probability to be funded by market, and might become 'endangered species in science'. Hence, it is important that policymakers and public management design apt research policy and strategy to support fruitful market-oriented funding mechanisms to balance applied, technological services and basic research, *without compromising future technological, economic and social progress of societies*.

We believe that the scientometric approach here provides preliminary results to understand current strategic change of the scientific portfolio of public research units based on a fruitful coexistence of public and market-oriented funding mechanisms. The conclusions of this study are of course tentative because we know that fast-changing and turbulent markets tend to generate several consequences on organizational behaviour of public research labs, difficult to capture as a whole with quantitative analyses, as a consequence no rules and/or results will be true in all situations.

References

Abbott, M., & Doucouliagos, C. (2003). The efficiency of Australian universities: A data envelopment analysis. *Economics of Education Review, 22*(1), 89–97.

Abramo, G., Cicero, T., & D'Angelo, C. A. (2011). A field-standardized application of DEA to national-scale research assessment of universities. *Journal of Informetrics, 5*(4), 659–667.

Anderson, T. R., Daim, T. U., & Lavoie, F. F. (2007). Measuring the efficiency of university technology transfer. *Technovation, 27*(5), 306–318.

Athanassopoulos, A., & Shale, E. (1997). Assessing the comparative efficiency of higher education institutions in the UK by means of data envelopment analysis. *Education Economics, 5*(2), 117–134.

Carayol, N., & Matt, M. (2004). The exploitation of complementarities in scientific production process at the laboratory level. *Technovation, 24*(6), 455–465.

Chambers, R. G., Chung, Y., & Färe, R. (1996). Benefit and distance function. *Journal of Economic Theory, 70*(2), 407–419.

Chambers, R. G., Chung, Y., & Färe, R. (1998). Profit, directional distance function and Nerlovian efficiency. *Journal of Optimisation Theory and Applications, 98*(2), 351–364.

Coccia, M. (2001). A basic model for evaluating R&D performance: Theory and application in Italy. *R&D Management, 31*(4), 453–464.

Coccia, M. (2004). New models for measuring the R&D performance and identifying the productivity of public research institutes. *R&D Management, 34*(3), 267–280.

Coccia, M. (2005). A taxonomy of public research bodies: a systemic approach. *Prometheus –The journal of issues in technological change, innovation, information economics, communications and science policy, 23*(1), 63–82.

Coccia, M. (2008a). New organizational behaviour of public research institutions: Lessons learned from Italian case study. *International Journal of Business Innovation and Research, 2*(4), 402–419.

Coccia, M. (2008b). Measuring scientific performance of public research units for strategic change. *Journal of Informetrics, 2*(3), 183–194.

Coccia, M. (2009a). Research performance and bureaucratization within public research labs. *Scientometrics, 79*(1), 93–107.

Coccia, M. (2009b). Bureaucratization in public research institutions. *Minerva, A Review of Science, Learning and Policy, 47*(1), 31–50.

Coccia, M. (2012). Organization and strategic change of public research institutions. In: L. Greenfeld (Ed.), *The ideals of Joseph Ben-David* (Ch. 5, pp. 73–96). Piscataway, NJ: Transaction Publishers.

Coccia, M., & Cadario, E. (2014). Organisational (un)learning of public research labs in turbulent context. *International Journal of Innovation and Learning, 15*(2), 115–129.

Coccia, M., & Rolfo, S. (2002). Technology transfer analysis in the Italian National Research Council. *Technovation, 22*(5), 291–299.

Coccia, M., & Rolfo, S. (2007). How research policy changes can affect the organization and productivity of public research institutes. *Journal of Comparative Policy Analysis, Research and Practice, 9*(3), 215–233.

Coccia, M., & Rolfo, S. (2008). Strategic change of public research units in their scientific activity. *Technovation, 28*(8), 485–494.

Coccia, M., & Rolfo, S. (2009). Project management in public research organization: strategic change in complex scenarios. *International Journal of Project Organisation and Management, 1*(3), 235–252.

Coccia, M., & Rolfo, S. (2010). New entrepreneurial behaviour of public research organizations: Opportunities and threats of technological services supply. *International Journal of Services, Technology and Management, 13*(1/2), 134–151.

Coccia, M., & Rolfo, S. (2013). Human Resource Management and Organizational Behavior of Public Research Institutions. *International Journal of Public Administration, 38*(4), 256–268.

Coelli, T., Prasada Rao, D. S., & Battese, G. E. (1989). *An Introduction to efficiency and productivity analysis*. Boston: Kluver Academic.

Crow, M., & Bozeman, B. (1998). *Limited by design*. Columbia University Press, New York: R&D Laboratories in the U.S. National Innovation System.

Czarnitzki, D., Hussinge, K., & Schneider, C. (2011). Commercializing Academic Research: The Quality of Faculty Patenting. *Industrial and Corporate Change, Industrial and Corporate Change, 20*(5), 1403–1437.

Czarnitzki, D., & Kraft, K. (2012). Spillovers of Innovation Activities and Their Profitability. *Oxford Economic Papers, 64*, 302–322.

Czarnitzki, D., & Thorwarth, S. (2012). The contribution of in-house and external design activities on product market performance. *Journal of Product Innovation Management, 29*(5), 878–895.

Czarnitzki, D., & Toole, A. (2010). Is there a trade-off between academic research and faculty entrepreneurship? Evidence from US NIH supported biomedical researchers. *Economics of Innovation and New Technology, 19*(5/6), 505–520.

Falavigna, G., & Manello, A. (2014). External funding, efficiency and productivity growth in public research: The case of the Italian National Research Council. *Research Evaluation, 23*, 33–47.

Färe, R., & Grosskopf, S. (2000). Theory and application of directional distance function. *Journal of Productivity Analysis, 13*(2), 93–103.

Färe, R., Grosskopf, S., Lovell, C. A. K., & Pasurka, C. (1989). Multilateral productivity comparison when some output are undesirable: A non parametric approach. *The Review of Economics and Statistics, 71*(1), 90–98.

Färe, R., Grosskopf, S., & Pasurka, C. (2007). Environmental production function and environmental directional distance function. *The International Journal, 32*(7), 1055–1066.

Gioia, D. A., & Chittipeddi, K. (1991). Sensemaking and Sensegiving in Strategic Change Initiation. *Strategic Management Journal, 12*(6), 433–448.

Gläser, J., Laudel, G., Hinze, S., & Butler, L. (2002). *Impact of evaluation-based funding on the production of scientific knowledge: What to worry about, and how to find out*. Karlsruhe, Germany: Fraunhofer ISI.

Goldfarb, B. (2008). The Effect of Government Contracting on Academic Research: Does the source of funding affect scientific output? *Research Policy, 37*(1), 41–58.

Groot, T., & García-Valderrama, T. (2006). Research quality and efficiency. Analysis of assessments and management issues in Dutch economics and business research programs. *Research Policy, 35*(9), 1362–1376.

Gulbrandsen, M., & Smeby, J. C. (2005). Industry funding and university professors' research performance. *Research Policy, 34*(6), 932–950.

Hicks, D. (2012). Performance-based university research funding systems. *Research Policy, 41*(2), 251–261.

Kao, C., & Hung, H. T. (2008). Efficiency analysis of university departments: An empirical study. *The International Journal of Management Science (Omega), 36*(4), 653–664.

Laudel, G. (2006). The art of getting funded: How scientists adapt to their funding conditions. *Science and Public Policy, 33*(7), 489–504.

Lepori, T. J., & Larédo, P. (2007). Changing patterns of public research funding in France. *Science and Public Policy, 34*(6), 389–399.

Llerena, P., Matt, M., & Schaeffer, V. (2003). The evolution of French research policies and the impacts on the universities and public research organizations. In A. Geuna, A. J. Salter, & W. E. Steinmueller (Eds.), *Science and innovation: Rethinking the rationales for funding and governance* (pp. 147–168). Cheltenham: Edward Elgar.

Mitsutaka, M., Yokota, S., Naito, K., & Itoh, J. (2010). Development of a model to estimate the economic impacts of R&D output of public research institutes. *R&D Management, 40*(1), 91–100.

Musselin, C. (2007). The transformation of academic work: Acts and analysis. *Center for studies in higher education*, No. 4. Berkeley: University of California.

Nagy, S. G., Kováts, G., & Németh, A. O. (2014). Governance and Funding of Higher Education–International Trends and Best Practices. *Procedia—Social and Behavioral Sciences, 116*, 180–184.

Nelson, R. R. (2005). *The limits of market organization*. New York: Russel Sage.

Picazo-Tadeo, A. J., & Prior, D. (2009). Environmental externalities and efficiency measurement. *Journal of Environmental Economics and Management, 90*(11), 3332–3339.

Sanz-Menéndez, L., & Cruz-Castro, L. (2003). Coping with environmental pressures: Public research organisations responses to funding crises. *Research Policy, 32*(8), 1293–1308.

Sarrico, C. S., Teixeira, P. N., Rosa, M. J., & Cardoso, M. F. (2009). Subject mix and productivity in Portuguese universities. *European Journal of Operational Research, 197*(1), 287–295.

Schuetze, H. G. (2007). Research universities and the spectre of academic capitalism. *Minerva, XLV*(4), 435–443.

Slaughter, S., & Leslie, L. L. (1997). *Academic capitalism: Politics, policies*. The Johns Hopkins University Press, Baltimore MD: and the Entrepreneurial University.

Stephan, P. (2012). *How economics shapes science*. Harvard: Harvard University Press.

Thijs, B., & Glänzel, W. (2008). A structural analysis of publication profiles for the classification of European research institutes. *Scientometrics, 74*(2), 223–236.

Tucker, J. M., Dunlap, D. R., & Friar, J. H. (2012). The university entrepreneur: A census and survey of attributes and outcomes. *R&D Management, 42*(5), 401–419.

Tuzi, F. (2005). Useful science is good science: Empirical evidence from the Italian National Research Council. *Technovation, 25*(5), 505–512.

Van Looy, B., Ranga, M., Callaert, J., Debackere, K., & Zimmermann, E. (2004). Combining entrepreneurial and scientific performance in academia: Towards a compounded and reciprocal Matthew-effect? *Research Policy, 33*(3), 425–441.

Viale, R., & Etzkowitz, H. (2004) Third academic revolution: Polyvalent knowledge; the DNA of the triple helix, www.triplehelix5.com.

Washburn, J. (2005). *University Inc.: The corporate corruption of higher education*. New York: Basic Books.

Whittington, R. (1991). Changing control strategies in industrial R&D. *R&D Management, 21*(1), 43–53.