Analysis of the resource concentration on size and research performance. The case of Italian National Research Council over the period 2000-2004

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Abstract. Nowadays the Government of industrialised countries, in presence of reduced public funds, has to manage the public research laboratories to increase the efficiency and research performance, necessary to the competitiveness of firms and of economic systems. The purpose of this paper is to investigate the relationships between size and performance of public research organisations within of the Italian national system of innovation, for the period 2000-2004, which is characterised by two different research policies. The comparative analysis shows that the results can supply useful information to policy makers on the behaviour of these structures. The new research policy based on merger among the research institutes generates higher research performance and scale economies. However some elements suggest to be cautious about this relationship and to further investigate.

Key words: Research Laboratories, R&D Performance, Size, Public Research, Research Structure, Research Policy

JEL Classification: C10, C20, C30, H10, H41, H50, L30

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INDEX

Introduction ................................................................................................................................................ 5

1. Theoretical framework........................................................................................................................... 5

2. Comparative policy analysis of the Italian National Research Council Laboratories (Cnr): Data and Methodology........................................................................................................... 6

3. Results................................................................................................................................................. 7
   3.1. Size- research performance before the merger (2000-period) ....................................................... 7
   3.2. Size- research performance after the merger among the institutes (2004-period)....................... 8
   3.3. T-Test to countercheck the results ................................................................................................ 10

4. Concluding remarks ........................................................................................................................... 11

References .............................................................................................................................................. 13

Introduction

The sector of public research is made up, according to Senker (2001), of those institutions that deal with civil research and benefit mainly from public financing. These organisations are of public property and their chief purpose is to divulge the results of their researches (in other words, military research is excluded). Etzkowitz and Leydesdorff (2000) claim, referring to their own theory of the triple helix, that nowadays universities and public research bodies play a fundamental role in the production of scientific knowledge (such as inventions), necessary to the development of a competitive economic system in a society based more and more on knowledge. Studies about these institutions in many industrialised countries, among which Italy, the United Kingdom, and so on, show a growing interest in evaluating the effects of size on research performance. These studies can mirror the interest shown by the Government in restructuring this sector through suitable research policy (Tassey 2001) to assign clear objectives to public research structure so that it is managed in an effective and efficient way in light of reduced public funds. This situation has pushed many countries, for instance the United Kingdom (Senker 2001) and Italy (Coccia and Rolfo 2002), to increase the size of these structures, reducing the activities in certain scientific fields and at the same time expanding them in other fields. Throughout this process of transformation, the State, which plays the role of the principal according to the terminology used in theory of principal-agent, pursues objectives that are often in conflict with those of research bodies (i.e. agents), especially due to a defective knowledge of the information activities of the latter. Within such a scenario, the purpose of this paper is to investigate the relationship between size and performance of the Italian public research laboratories, making a comparison of two different research policies referred to 2000 and 2004, i.e. before and after a structural reform of the Italian public research system. This research can supply useful information on the behaviour of these structures over a period characterised by a new research policy focused on the achievement of a critical mass of the research bodies in order to improve the efficiency of the national system of innovation (David et al. 1999). In relation to this, section 2 describes the theoretical framework, section 3 develops the methodology of the analysis, the data, and their sources while section 4 presents and the main results drawn from the comparative policy analysis of the Italian situation. The concluding remarks include a discussion and some research policy implications.

1. Theoretical framework

The need to improve the performance of the research bodies has generated new fields of study that evaluate research both at a macroeconomic level and at the level of research laboratories (Coccia 2001; 2004), of research teams and researchers (Sirilli 2000; Broadus 1987; Garfield 1979; Luwel et al. 1999; Pritchard 1969; Kerssens-van Drongelen and Bilderbeek 1999).

Main studies and reviews about the effects of size on research performance have been carried out by Martin et al. (1993), Von Tuzelmann et al. (2003), and Johnes and Johnes (1993). Some researches focused the returns from research with respect to the scale of production. The theory of increasing returns in scientific research was at the basis of the public policies applied in the United Kingdom towards the end of the seventies, which aimed to concentrate research resources in large laboratories (Johnston 1993; 1995). The remarks in favour of the existence of economies of scale (internal) in scientific production, are: a) critical mass (size) below which the researchers cannot activate significant cooperative relations; b) inseparable effects of some inputs; c) administrative activity characterised by fixed costs with respect to the volume of activity; d) the research projects produce differing results over time and the larger research bodies can invest in major projects.

On the basis of these facts, it would be desirable for resources to be transferred from smaller laboratories to larger ones (through mergers and acquisitions), characterised by higher production rates that would increase the production of the entire economic system. The theory of increasing returns however is not supported by econometrics research. The studies of Griliches and
Adams (1998) have shown that scientific production in the principal universities shows a linear relationship between the output and the size of the university in terms of budget (Hoare 1995). Narin and Hamilton (1996) did not find significant support for the theory of increasing returns for scientific research, while Johnston (1993) in his studies did not find significant economies of scale.

Other studies on the performance of research teams show that some support an increase, others a reduction, and yet others a combination of the two (Hare and Wyatt 1988). Hicks and Skea (1989) analysed the relationship between size and output suggest that although the larger departments are more productive, this dependence is extremely weak and can be easily explained by characteristics not linked to size.

Recently Bonaccorsi and Daraio (2002) state that the existence of increasing returns is one of the theoretical pillars of public policies and if economies of scale exist, the minimum efficient scale (MES) is positioned at relatively low levels, measured by the sizes of the research team rather than that of the major institutions, as the laboratories or the institutes. In any case the lack of definitive response to the main answer concerning the size of the public research labs represents not only a problem from the managerial point of view, but essentially a serious limit at the policy level (Crow and Bozeman 1998).

2. Comparative policy analysis of the Italian National Research Council Laboratories (Cnr): Data and Methodology

Many European countries have a secondary network of public research (Charles and Howells 1996), operating alongside the universities, and represented by both bodies specialised in scientific disciplines or applications, and generalist bodies which cover the entire fields of scientific and humanistic research. The latter, almost entirely founded in the first half of the last century, are generally divided into institutes and laboratories of varying size and location. Two patterns can be highlighted in Europe: the German model represented by great laboratories (100-200 permanent staff) belonging to famous research organisations as the Max Planck Society or the Fraunhofer Society or the more recent Leibniz and Helmholz Societies. At the contrary in France are prevailing the small mixed units set up by the French National Research Council (CNRS) in the universities. Until the end of the nineties Italy mainly pursued for its main research organisation, the National Research Council (Cnr) founded in 1923 on the model of the Kaiser Wilhelm Society (now Max Planck), a mixed solution represented by research institutes with their own payroll employees and centres set up in the universities and staffed by Cnr and university employees. At the end of the nineties the financial cuts to the public research budgets, of the Governments caused a substantial block in staff turnover in the existing Cnr labs (around 300 institutes and centres) with a decrease of their size and an increase of the average age of the employees. The seriousness of the situation forced in 1999 the Italian government to totally reorganise the institution, also dealing with the question of size. The objective was clear and the process of reorganisation (started in 2001), amongst the various changes, has led to the closure of 32 laboratories and the mergers of the remaining 278 scientific bodies in 108 new institutes.

The aim of this paper is to check whether public research laboratories with the medium-large size have higher levels of research performance than the smaller ones, making a comparative policy analysis before the merger among the Italian Cnr institutes (2000), and after the merger (2004 period). The analysis is carried out with evaluations of the results using two research methods: regression and inference analysis. All data analyzed are from the official documents of the Italian National Research Council: Report, 2000 and 2004 period. The analysis has been carried out using as a proxy of the size the number of employees operating in the laboratories, while the numbers of the domestic and international publications (outputs) of the research laboratories are a proxy of the research performance:

\[
\text{NUMBER OF PUBLICATIONS} = \text{NUMBER OF INTERNATIONAL PUBLICATIONS} + \text{NUMBER OF PUBLICATION WITH DOMESTIC DIFFUSION}
\]
The first step was a screening of the data to check the normality of the distributions, the presence of outliers and anomalous values, necessary conditions for proceeding with the inference, correlation and regression analysis. After that, we tested the cause-effect relationship among size and research performance by the formulation of econometric models of regression which study the intensity and the linear relationship existing between the:

\[ Y = \text{dependent variable} = \text{research performance} = \text{numbers of publications} \]

and

\[ x = \text{explanatory variable} = \text{indicator of size} = \text{number of employees} \]

Therefore the regression model is the following (Spanos 1986):

\[ Y = \alpha + \beta x + \varepsilon \]

The results with the regression analysis have been checked by the inference on the arithmetic mean. We calculate the mean of publications (performances) in 2000 (before the merger) and in 2004 (after the merger among the institutes). After that, using the T-test, it is possible to verify the null hypothesis of equality between the arithmetic mean of the two years at probability level \( p=0.99 \).

The complexity and abundance of calculations, due to the high number of variables, has been overcome thanks to the application of the SPSS® statistical package, which has provided all the results described and analysed in the following sections.

3. Results

3.1. Size- research performance before the merger (2000-period)

The organisational structure of the Cnr in 2000 was based on 310 institutes and centres of small size similar in terms of size and organisation to the France CNRS. The research structure was divided into 15 scientific fields: 1) Mathematics; 2) Physics; 3) Chemistry; 4) Medicine and biology; 5) Geology and mining; 6) Agriculture; 7) Engineering and architecture; 8) History, philosophy and philology; 9) Law and politics; 10) Economics, sociology and statistics; 11) Innovation and technology; 12) Information technology; 13) Environment and habitat; 14) Biotechnologies and molecular biology; 15) Cultural heritage.

The 310 Cnr scientific laboratories had an arithmetic mean of employees of 19.84 per research institute, and arithmetic mean of number of publications of 31.93 per structure. The variables analysed showed distribution normal. The dependent variable is the research performance \( Y \), measured by the number of publications, of the scientific laboratories, while the explanatory variable is the number of payroll researchers, which are a proxy of the size. The results are presented in the following tables (1-4).

<table>
<thead>
<tr>
<th>Table 1: Descriptive Statistics (2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Number of publications</td>
</tr>
<tr>
<td>Number of employees</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Correlations (2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of publications</td>
</tr>
<tr>
<td>Number of employees</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
<th>Number of publications</th>
<th>Number of employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of publications</td>
<td>310</td>
<td>310</td>
</tr>
<tr>
<td>Number of employees</td>
<td>310</td>
<td>310</td>
</tr>
</tbody>
</table>
Table 3: Model Summary \(^{a,b}\) (2000)

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of employees (^{c,d})</td>
<td>0.514</td>
<td>0.264</td>
<td>0.262</td>
<td>22.386</td>
</tr>
</tbody>
</table>

\(^a\) Dependent Variable: Number of publications  
\(^b\) Method: Enter  
\(^c\) Independent Variables: (Constant), Number of employees  
\(^d\) All requested variables entered

The equation estimated in the model 1 is the following:

\[
\hat{Y} = 18.194 + 0.692 \text{ (number of employees)}
\]

Table 4: Coefficients \(^a\) (2000)

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>T</th>
<th>Sig.</th>
<th>95% Confidence Interval For B</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
</tr>
<tr>
<td>1</td>
<td>Constant</td>
<td>18.194</td>
<td>1.822</td>
<td>9.986</td>
<td>0.000</td>
<td>14.609</td>
</tr>
<tr>
<td></td>
<td>Number of employees</td>
<td>0.692</td>
<td>0.066</td>
<td>0.514</td>
<td>10.523</td>
<td>0.000</td>
</tr>
</tbody>
</table>

\(^a\) Dependent Variable: Number of publications

3.2. Size- research performance after the merger among the institutes (2004-period)

The new organisation structure of Italian Cnr (since 2002), after a research policy of concentration of institutes, is based on 108 institutes of bigger size which have 191 decentralised units. They operate in five scientific fields: 1) Basic Sciences with 28 new institutes operating in the fields of mathematics, physics and chemistry; 2) Life Sciences, 33 new laboratories in the fields of medicine and biology, agriculture and molecular biology; 3) earth and environmental sciences, concerning geology, environment and habitat for a total of 10 labs; 4) Social and human sciences with 19 laboratories in the fields of history, philosophy and philology; juridical and political sciences; economics, sociology and statistics; cultural heritage; 5) The field of engineering and information-communication technology sciences is formed of 18 laboratories.

Therefore, the new Italian research policy seems to be focused on a organisational structure similar to the German model, but with a spread presence on the Italian territory (108 institutes and 191 units) that is unknown in the German public research organisations. The new Italian organisation is characterised by research groups physically dispersed, but now integrated within bigger laboratories than the old structures in 2000.

The 108 structures have a arithmetic mean of employees of 56.86 per research institute, and arithmetic mean of number of publications of 87.22 per structure. The variables analysed showed distribution normal. The results of single variable statistics and relationship between variables are presented in the following tables (5-8).
Table 5: Descriptive Statistics (2004)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of publications</td>
<td>87.222</td>
<td>58.929</td>
<td>108</td>
</tr>
<tr>
<td>Number of employees</td>
<td>56.861</td>
<td>33.791</td>
<td>108</td>
</tr>
</tbody>
</table>

Table 6: Correlations (2004)

<table>
<thead>
<tr>
<th></th>
<th>Number of publications</th>
<th>Number of employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of publications</td>
<td>1.000</td>
<td>0.659</td>
</tr>
<tr>
<td>Number of employees</td>
<td>0.659</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table 7: Model Summary a,b (2004)

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables</th>
<th>Entered</th>
<th>Removed</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of employees c,d</td>
<td>0.659</td>
<td></td>
<td>0.434</td>
<td>0.429</td>
<td>44.549</td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: Number of publications
b. Method: Enter
c. Independent Variables: (Constant), Number of employees
d. All requested variables entered

The equation estimated in the model 1 is:

\[ \hat{Y} = 21.908 + 1.149 \text{(number of employees)} \]

The relationship suggests that each additional employee add about 1.149 to the number of publications.

Table 8: Coefficients a (2004)

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>95% Confidence Interval For B</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of employees</td>
<td>21.908</td>
<td>8.420</td>
<td>5.215</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td>Lower Bound</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>Sig.</td>
<td>Upper Bound</td>
<td>Tolerance</td>
</tr>
<tr>
<td></td>
<td>1.149</td>
<td>0.127</td>
<td>0.659</td>
<td>0.896</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Number of publications
3.3. **T-Test to countercheck the results**

The variable number of publications in 2000 and 2004 has normal distribution that makes it possible to carry out the inference correctly. The idea in this section is to evaluate the performance of the research bodies in relation to their size from a different point of view. In particular, we would like to check, at the probability level \( p=0.99 \), the null hypothesis that the arithmetic mean of the research performance, measured by number of publications, in the period 2000 is equal to those of 2004 period, against the alternative hypothesis that the arithmetic mean of the number of publications, in the 2004 is higher than the 2000 due to Italian research policy based on the concentration among the institutes. In symbols \( H_0 : \bar{x}_{2000} = \bar{x}_{2004} \). The most feasible alternative hypothesis is that research performance increased due to the merger operations \( H_0 : \bar{x}_{2004} < \bar{x}_{2000} \). T-test is conducted on the left-hand tail of the \( t \)-distribution. More precisely the rejection region will be that \( t \) assumes values above \( t_{\alpha,0.01} \).

The results are shown in the following tables (9-10).

**Table 9: One-sample Statistics (T-Test)**

<table>
<thead>
<tr>
<th></th>
<th>N.</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error of Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of publications 2000</td>
<td>310</td>
<td>31.926</td>
<td>26.059</td>
<td>1.480</td>
</tr>
<tr>
<td>Number of publications 2004</td>
<td>108</td>
<td>87.222</td>
<td>58.929</td>
<td>5.671</td>
</tr>
</tbody>
</table>

**Table 10: One-sample Statistics (T-Test)**

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>99% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Number of publications 2000</td>
<td>21.571</td>
<td>309</td>
<td>0.000</td>
<td>31.926</td>
<td>28.090</td>
</tr>
<tr>
<td>Number of publications 2004</td>
<td>15.382</td>
<td>107</td>
<td>0.000</td>
<td>87.222</td>
<td>72.351</td>
</tr>
</tbody>
</table>

Therefore:

\[
t = \frac{31.926 - 87.222}{42.4941 \sqrt{\frac{1}{310} + \frac{1}{108}}} = -11.646
\]

The degree of freedoms are: \( n_{2000} + n_{2004} - 2 = 416 \). The theoretical value of \( t_{\alpha,0.01} = 2.576 \). The \( t \) calculated is considerably higher than 2.576 and therefore falls within the rejection region. In other words, at the probability level \( p=0.99 \), the research performance of the research institutes in the 2004 period (with larger size) is higher than the research performance of laboratories in 2000 and with smaller size. It is reasonable to think that the difference in research performance between the two years...
where the laboratories have a different size can be attributed to a systematic effect of the composition of the scientific fields (structure). Then, the concentration of research labs produces important scale economies.

4. Concluding remarks

This research shows like, within the Italian National Research Council, the comparison of two different statistical methodologies achieves similar results. The policy of concentration among the Italian public research institutes seems to have generated main economies of scales: in fact in 2004 the research performance of the structures is 1.149, approximately double respect to the 2000 period when it was of about 0.692. Therefore, we could conclude that in the public research bodies there is a positive relationship between the increase in the size and the increase in research performance. However this result seems to be in contrast with previous researches, concerning the Cnr, carried out with different methodologies (Coccia and Rolfo 2002a; Bonaccorsi and Daraio 2003).

A main remark is that the real situation of the actual Italian national system of innovation shows as the research performances can be affected by several factors, which are more powerful then the size. The policy of concentration has been carried out only from a formal point of view because the labs have preserved the old location. In fact, although nowadays there are 108 new institutes, these often have several (2-10) decentralised units spread on the territory and far from the headquarter. This situation creates some diseconomies of scale due to the increased costs of co-ordination, with a negative influence on the research performances. Probably only in the long term we could appreciate the positive effects of a growing scientific integration of the different research groups within the new institutes.

Therefore how can we explain the increased performances of Cnr institutes in 2004? When studying the variations in the performance of an organisation (Ramsden 1994), in relation to the changes in a single factor of the organisational system, it is necessary that the other elements of the system remain unchanged. Otherwise the variation in performance could be due to these changes, rather than to the variation in the factor we are studying. It is impossible to be certain that other variables are fixed in the dynamic system (as research laboratories) when the size changes, because a variation in size is usually accompanied by variations and changes to the entire organisational system. It is therefore arbitrary to attribute changes in performance merely to changes in size. The scientific production of a research laboratory is a complex process, a combination of factors, of which it is difficult to isolate the action.

There are some elements (connected each other) that can display the increase in the research performances such as: 1) the autonomy of each structure to carry out the scientific research also starting new projects on a contractual base; 2) a process of evaluation that have pushed the Italian researchers within the new 108 institutes to have a different approach towards the environment and the market (Bozeman and Crow 1990) that is now seen as a main financial resource.

These elements, on the managerial side, have generated a new operational attitude of the Institutes that act as quasi-firms “with many characteristics of the business firm, except for the profit motive” (Viale and Etzkowitz 2004); this new behaviour and structure of the institutes have produced, at Macro level, the effect showed in figure 1: an inversion of the trend of the principle financial resources of the research laboratories with an increase of the self-financing.

We can also remark that this positive trend of figure 1 may have negative aspects as already observed by Hare and Wyatt (1992) in the United Kingdom at the end of the seventies when to face a cut of the public financial resources the research and academic institutions moved towards activities capable of capturing funds from the market. This transformed the research institutes into organisations focused on consultancy and applied research, with negative repercussions on basic research and therefore on the long-run development of the country (Callon and Foray 1997). But if these risks at the moment do not appear within the Italian Cnr (as stated by the increase of the publications), at the
contrary it is possible examine the presence among the Cnr institutes of external and internal diseconomies, such as the co-ordination costs due to the presence of organisational decentralised units (staff missions, duplication of libraries and services, ...). For this reason the Government has issued in 2003 a new law to reform again the Cnr. This rationalisation is based on a grouping process of laboratories and the creation of new co-ordination structures similar to the departments of CNRS in France and the research alliances of the Fraunhofer Society in Germany.

Moreover the public research sector is going through, in all industrialised countries, a rationalisation that, according to Loredo and Mustar (2004), can overcome the institutional differences among universities and public laboratories and converge on some typologies of research units characterised by common “activity profiles” with “only a limited relationship to their institutional affiliations” and their countries. This process of creation of the triple helix is strictly linked to the emergence of polyvalent roles within the universities and the research organisations with a variety of models around the world (Viale and Etzkowitz 2004). In this evolution while the Italian universities act as uncertain and late followe, the Cnr has been rudely plunged by the government in a strong challenge: accomplish a large range of missions from basic to applied research, from high education to technology transfer in a context of reducing public budget.

This is why rather than the problem of optimal size of the laboratories, it would be more correct to investigate the optimum combination of inputs, of which scientific production is the principal output. In fact, when we say that large size generates internal and external economies, we suggest that the organisational structure, which is intrinsic to large size, brings economic advantages. Observing statistics from the economic system it is possible to state that while the number of large firms has grown, there are numerous medium and small firms that exist and prosper. The same is true in the research fields where a wide number of small and medium laboratories exist, and are efficient within some fields such as economics, psychology, and so forth. This proves that every size has its advantages and it is improbable that a particular size – whether large or small – will overtake all others.
The scale economies are valid to a certain point, if we admit that it is possible to isolate with certainty the influence of size on costs and therefore to be able to study the behaviour of costs in relation to the variation in size. Although large sizes may be more economical in some circumstances, there are certainly limits above which size becomes a synonym for inefficiency with internal and external diseconomies of scale. In fact the cost of some Italian institutes begin to increase, due to cost of co-ordination as already seen, and their large size can acquire the characteristic of administrative encumbrance known as “red tape” (Bozeman and Crow 1989; Gornitzka et al. 1998). In any case there is space for further research to investigate the influence of different factors on size and research performance, such as the autonomy of the institutes, the psychological stimulus of the researchers to reduction of the public funds and the new cultural approach to the market which characterise the laboratories as quasi-firms. Research is widely open.

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<thead>
<tr>
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<th>Issue Date</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>1/05</td>
<td>Gli approcci biologici nell’economia dell’innovazione</td>
<td>Mario Coccia</td>
</tr>
<tr>
<td></td>
<td>2/05</td>
<td>Sistema informativo sulle strutture operanti nel settore delle biotecnologie in Italia</td>
<td>Edoardo Lorenzetti, Francesco Lutman, Mauro Mallone</td>
</tr>
<tr>
<td></td>
<td>3/05</td>
<td>Analysis of the Resource Concentration on Size and Research Performance. The Case of Italian National Research Council over the Period 2000-2004</td>
<td>Mario Coccia and Secondo Rolfo</td>
</tr>
<tr>
<td></td>
<td>4/05</td>
<td>Le risorse pubbliche per la ricerca scientifica e lo sviluppo sperimentale nel 2002</td>
<td>Anna Maria Scarda</td>
</tr>
<tr>
<td></td>
<td>5/05</td>
<td>La customer satisfaction dell’URP del Cnr. I casi Lazio, Piemonte e Sicilia</td>
<td>Gian Franco Corio</td>
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<tr>
<td></td>
<td>6/05</td>
<td>La comunicazione integrata tra uffici per le relazioni con il pubblico della Pubblica Amministrazione</td>
<td>Gian Franco Corio</td>
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<tr>
<td></td>
<td>7/05</td>
<td>Un’analisi teorica sul marketing territoriale. Presentazione di un caso studio. Il “consorzio per la tutela dell’Asti”</td>
<td>Maria Marenna</td>
</tr>
<tr>
<td></td>
<td>8/05</td>
<td>Una proposta di marketing territoriale: una possibile griglia di analisi delle risorse</td>
<td>Gian Franco Corio</td>
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<tr>
<td></td>
<td>9/05</td>
<td>Analisi e valutazione delle performance economico-tecnologiche di diversi paesi e situazione italiana</td>
<td>Mario Coccia and Mario Taretto</td>
</tr>
<tr>
<td></td>
<td>10/05</td>
<td>The patenting regime in the Italian public research system: what motivates public inventors to patent</td>
<td>Bianca Potì and Emanuela Reale</td>
</tr>
<tr>
<td></td>
<td>11/05</td>
<td>Changing patterns in the steering of the University in Italy: funding rules and doctoral programmes</td>
<td>Bianca Potì and Emanuela Reale</td>
</tr>
<tr>
<td></td>
<td>12/05</td>
<td>Una “discussione in rete” con Stanley Wilder</td>
<td>Carla Basili</td>
</tr>
<tr>
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<td>New Tools for the Governance of the Academic Research in Italy: the Role of Research Evaluation</td>
<td>Bianca Potì and Emanuela Reale</td>
</tr>
<tr>
<td></td>
<td>14/05</td>
<td>Product Differentiation, Industry Concentration and Market Share Turbulence</td>
<td>Catherine Matraves, Laura Rondi</td>
</tr>
<tr>
<td></td>
<td>15/05</td>
<td>Riforme del Servizio Sanitario Nazionale e dinamica dell’efficienza ospedaliera in Piemonte</td>
<td>Chiara Canta, Massimiliano Piacenza, Gilberto Turati</td>
</tr>
<tr>
<td></td>
<td>16/05</td>
<td>SERIE SPECIALE IN COLLABORAZIONE CON HERMES: Struttura di costo e rendimenti di scala nelle imprese di trasporto pubblico locale di medie-grandi dimensioni</td>
<td>Carlo Cambini, Ivana Paniccia, Massimiliano Piacenza, Davide Vannoni</td>
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