EUI WORKING PAPERS

RSCAS No. 2006/12

The Production of Scientific Knowledge in Italy: Evidence in Theoretical, Applied and Technical Sciences

Pier Paolo Patrucco

EUROPEAN UNIVERSITY INSTITUTE
Robert Schuman Centre for Advanced Studies
European Forum 2004-2005

EUROPEAN UNIVERSITY INSTITUTE, FLORENCE
ROBERT SCHUMAN CENTRE FOR ADVANCED STUDIES

The Production of Scientific Knowledge in Italy: Evidence in Theoretical, Applied And Technical Sciences

PIER PAOLO PATRUCCO

EUI Working Paper **RSCAS** No. 2006/12
BADIA FIESOLANA, SAN DOMENICO DI FIESOLE (FI)

ISSN 1028-3625

Printed in Italy in March 2006
European University Institute
Badia Fiesolana
I – 50016 San Domenico di Fiesole (FI)
Italy
http://www.iue.it/RSCAS/Publications/
http://cadmus.iue.it/dspace/index.jsp

Robert Schuman Centre for Advanced Studies

The Robert Schuman Centre for Advanced Studies carries out disciplinary and interdisciplinary research in the areas of European integration and public policy in Europe. It hosts the annual European Forum. Details of this and the other research of the centre can be found on:
http://www.iue.it/RSCAS/Research/

Research publications take the form of Working Papers, Policy Papers, Distinguished Lectures and books. Most of these are also available on the RSCAS website:
http://www.iue.it/RSCAS/Publications/

European Forum

The European Forum was set up by the High Council of the EUI in 1992 with the mission of bringing together at the European University Institute, for a given academic year, a group of experts to conduct comparative and interdisciplinary research on a specific topic, which is chosen annually, under the supervision of annual scientific director(s).

This Working Paper has been written in the context of the 2004-2005 European Forum programme on 'The Role of Universities in the Innovation Systems', the overall direction and coordination of which was carried out by Professor Rikard Stankiewicz, EUI, and Dr Aldo Geuna, EUI and SPRU, University of Sussex.

The growing role of universities in the 'knowledge economy' is well known. A dynamic and well-balanced academic system is a key engine of innovation and economic development. Doubts persist however as to whether Europe's universities are fully capable of fulfilling that role. The members of the Forum approached these issues by focusing on the following research themes: (1) Universities and the changing dynamics of knowledge production; (2) Patterns of the division of labour in research and innovation system; (3) The internal organisation of academic systems: tensions and adaptations; and (4) Diversity, innovativeness, and the governance of academic systems.

For further information:

E-mail: forinfo@iue.it

http://www.iue.it/RSCAS/Research/EuropeanForum/Index.shtml

Abstract

The paper presents preliminary empirical evidence on the production of scientific knowledge in Italy, in theoretical sciences (physics), applied sciences (chemistry) and technical sciences (engineering and petrology). It elaborates on an original dataset of publications and citations for 2673 Italian researchers, distributed across 61 universities, covering the years between 1990 and 2004. According to a well-established tradition of studies in the economics of science, the results show that individual distribution is very much asymmetric, with very few researchers accounting for a greater amount of scientific output. More interestingly, the paper also shows that there are important differences in terms of asymmetric distribution when comparing the different disciplines, universities and academic positions of the researchers. These differences open the room for interpretation in terms of two main factors. Firstly, the different disciplines can be characterised by specific knowledge bases, learning practices, organisation of scientific labour, and communication norms. Secondly, specific weaknesses in the hiring, incentives and monitoring schemes at the discipline and university level can explain different degrees of asymmetry. Both these factors have important implications for a research agenda on the governance of science. Finally, the paper shows that, at the aggregate level, publications benefit from concentration of R&D expenditures only to a minor extent, with a limited effect of externalities stemming from R&D investments. The scope for the concentration of R&D resources can therefore be questioned.

Keywords
Economics of science; Italy; Scientific knowledge; Scientific productivity; University

1. INTRODUCTION

The fact that the production of scientific knowledge is very asymmetric and skewed across both individuals and institutions is one of the few consolidated results in the economics and sociology of science. The distribution of scientific production across individuals is by no means normal but it is well described by a Pareto distribution, where the largest proportion of output is accounted for by a relatively small number of very productive researchers (Lotka, 1926; Katz, 1999; Merton, 1968). At the institutional level, scientific production and productivity are often skewed according to the role played by ‘stars’, rather than, for instance, by the scale of the research institutions (Zucker et al., 1998).

In this context, the paper elaborates upon an original dataset of individual publications and citations of 2673 Italian researchers in theoretical, applied and technical sciences, distributed across 61 universities. The object of this paper is to provide empirical evidence on the characteristics of the individual distribution of scientific production according to the different disciplines, universities and academic positions of the single researchers.

More precisely, the paper compares the individual distribution of scientific production across disciplines, universities and positions in order to 1) show to what extent scientific production is asymmetric or not; 2) investigate whether the various disciplines, universities and individual positions are characterised by different levels of asymmetry, or on the contrary the variance across disciplines, universities and positions is limited; 3) reveal the differences in terms of the proportion of very productive researchers compared to the proportion of less productive ones.

In this sense, the novelty of the paper lies in distinguishing the individual distribution of scientific production in terms of disciplines, universities and academic positions. If and when the differences in terms of asymmetric distribution of scientific output across disciplines, universities and positions were high, such differences can be explained according to two main factors. Firstly, discipline specificities can matter, especially in terms of idiosyncratic characteristics of knowledge base, learning practices, models of organisation of scientific work and communication patterns that distinguish the different scientific fields. Secondly, difference can be explained in terms of more or less effective (or more or less weak) hiring, incentives and monitoring schemes at the discipline and university level: the more asymmetric the distribution of scientific knowledge, the weaker those schemes. The implications in terms of a research agenda on the governance of science can be relevant for both these factors. In particular, specific governance models should be identified according to the specificities showed by the different disciplines and academic positions.

Moreover, the analysis also compares (at the regional level) the amount of R&D expenditure with the number of publications, investigating to what extent scientific activity may benefit from the concentration of R&D resources in a given space.

The paper is organised as follows. Section 2 presents the empirical dataset and the methodology on which the paper is based. Section 3 shows the empirical results on the characteristics of the distribution of scientific production, comparing the different distribution of scientific production by disciplines, universities and academic positions. It also correlates, at the regional level, scientific output in terms of publications, with the amount of R&D investment. Section 4 puts forward an interpretative framework to provide a preliminary explanation of the empirical evidence, which can be also read as a research agenda on the implications for the governance of science. The conclusions summarise the main results and put these in the perspective of future research.

2. DATASET AND METHODOLOGY

The paper elaborates upon an original database made of 2673 Italian researchers (assistant, associate and full professors), distributed across 61 universities, active in the fields of chemistry (Physical chemistry; General and inorganic chemistry; Organic chemistry), engineering (Metallurgy; Material engineering; Electronics measurement), earth sciences (Petrology) and physics (Theoretical physics). These scientific fields were chosen firstly because in these fields, with the exception of physics, Italy has a scientific impact higher than the European average (CRUI, 2002). In this regard, such fields can be thought of as ‘best practices’ or ‘scientific champions’ in Italian science. Secondly, they represent quite well the traditional classification between theoretical science (Physics), applied science (Chemistry and), and technical or technology-oriented science (Petrology and Engineering),[1] characterised by codified, articulable and tacit knowledge bases respectively.[2] Here it may be interesting to compare the different fields, looking at the different characteristics, and eventually identifying some specificities, according to the knowledge base behind the different fields.

This database has been implemented using data from the Italian Ministry of University, Research and Technology (MIUR) and the 2673 researchers included in the database represent the universe of the researchers in those fields. For each researcher, the database provides information on their position [1) tenured assistant professors; 2) assistant professors without tenure; 3) tenured associate professors; 4) associate professors without tenure; 5) tenured full professors; 6) full professors without tenure],[3] the institution in which they are employed (university level), and the region in which the university is located.

This dataset has then been integrated with the number of publications and citations received by each researcher on ISI journals. In order to analyse scientific production for the different fields, two indicators for output will be used, namely the number of publications cited by articles published in ISI journals, and the number of citations received by such publications. The number of publications and citations refers to the period 1990-2004, and is based on the Science Citation Index elaborated by the ISI.[4]

The empirical analysis will show, through the simple count of publications and citations per researcher and the cumulative percentages of publications, citations and researchers, which are the characteristics of scientific production according to the different scientific fields, universities and academic positions. Moreover, it will show whether there are differences across fields, universities and academic positions in terms of asymmetry of the distribution and the proportion of more productive researchers, when compared to the proportion of the less productive ones.

Table 1 shows the distribution of researchers, publications and citations across the different scientific fields.

Here the larger fields are those in chemistry, which represent 25%, 23% and 18.5% of the population of researchers respectively. On the contrary, engineering sectors are relatively the smallest, covering 8%, 4% and 3% of the total researchers. These relative weights are, quite obviously, reflected also on the shares of publications and citations. More interestingly, when considering simple

1 Such classification has been confirmed by colloquiums with researchers in the fields. Although, just to anticipate one of the results of the paper, our simple descriptive statistics on the distribution of publications will show a relatively different picture. One in which physics and chemistry are more similar to each other and quite distinct from technological fields (i.e., engineering and petrology). In this respect, the idea of considering chemistry an applied science, which is indeed common also among scientists in the field, should be discussed in future research, analysing in-depth the nature of the different disciplines.

2 For this classification, see for instance the work by Cowan, David and Foray (2000).

3 In the Italian academic system, academic positions are ‘allocated’ by local competition. Once you win the local competition, you are given the position of, for instance, associate professor but without tenure. After 3 years, you go through a process of local and national evaluation of teaching and publishing activity undergone in the three years. If the response of this evaluation is positive, you get tenure. In principle, in terms of power and resources, there is quite a strong difference between assistant professors on the one hand, and associate and full professors on the other.

4 It is fair to say that the database on publications does not take into account multiple authorship. The importance of multiple authorship can vary according to scientific fields and may explain some of the differences in scientific production across fields. One of the next steps of this research will be the analysis of multiple authorship at least for a sample of researchers across disciplines.

productivity measures such as the number of publications per researcher, researchers in physics are the more productive, with 62 publications per researcher. Finally, when looking at the citation impact (N° citations/N° publications), again chemistry, and in particular the field of General and inorganic chemistry, is the one with the highest impact (6.79).

Table 1. The distribution of researchers, publications and citations across the different scientific fields

Scientific field	N° res	% res	N° publ	% publ	N° cit	% cit	Publ/res	Cit/res	Cit/publ
Metallurgy	88	3.29	2,365	1.68	9,874	1.17	26.88	112.20	4.18
Material engineering	220	8.23	7,375	5.24	31,680	3.74	33.52	144.00	4.30
Electronics measurement	108	4.04	1,890	1.34	4,949	0.58	17.50	45.82	2.62
Petrology	117	4.38	3,889	2.76	18,860	2.23	33.24	161.20	4.85
Physical chemistry	493	18.44	27,715	19.70	157,915	18.63	56.22	320.31	5.70
General and inorganic chemistry	621	23.23	37,598	26.73	255,292	30.12	60.54	411.10	6.79
Organic chemistry	670	25.07	37,871	26.92	234,397	27.66	56.52	349.85	6.19
Theoretical physics	356	13.32	21,956	15.61	134,494	15.87	61.67	377.79	6.13
TOTAL	2,673	100.00	140,659	100.00	847,461	100.00	52.62	317.04	6.02

Table 2 shows instead the distribution of researchers, publications and citations by region. Emilia Romagna is the region with the largest proportion of researchers (14%), publications (15.76%) and citations (17.69%), and also with the highest citation impact (6.76). in terms of scientific productivity, that is to say the ratio between publications and researchers, Tuscany and Piedmont are, among the largest regions, the more productive ones, with 62.55 and 60 publications per researcher respectively.

Table 2. The distribution of researchers, publications and citations across the Italian regions

Region	N° res	% res	N° publ	% publ	N° cit	% cit	Publ/res	Cit/res	Cit/publ
EMILIA-ROMAGNA	376	14.07	22167	15.76	149955	17.69	58.95	398.82	6.76
LOMBARDIA	346	12.94	18634	13.25	116200	13.71	53.86	335.84	6.24
TOSCANA	248	9.28	15513	11.03	100052	11.81	62.55	403.44	6.45
LAZIO	256	9.58	13229	9.41	77500	9.14	51.68	302.73	5.86
CAMPANIA	232	8.68	11050	7.86	63558	7.50	47.63	273.96	5.75
VENETO	182	6.81	9483	6.74	55365	6.53	52.10	304.20	5.84
PIEMONTE	152	5.69	9143	6.50	55815	6.59	60.15	367.20	6.10
SICILIA	207	7.74	7748	5.51	45357	5.35	37.43	219.12	5.85
PUGLIA	119	4.45	5460	3.88	25164	2.97	45.88	211.46	4.61
FRIULI	89	3.33	5436	3.86	34765	4.10	61.08	390.62	6.40
UMBRIA	75	2.81	4823	3.43	25439	3.00	64.31	339.19	5.27
SARDEGNA	97	3.63	4351	3.09	25739	3.04	44.86	265.35	5.92
LIGURIA	80	2.99	3621	2.57	16236	1.92	45.26	202.95	4.48
MARCHE	63	2.36	3396	2.41	16752	1.98	53.90	265.90	4.93
CALABRIA	54	2.02	2116	1.50	11115	1.31	39.19	205.83	5.25
TRENTINO-A.A.	30	1.12	1709	1.21	10775	1.27	56.97	359.17	6.30
ABRUZZO	32	1.20	1656	1.18	10505	1.24	51.75	328.28	6.34
BASILICATA	28	1.05	887	0.63	5771	0.68	31.68	206.11	6.51
MOLISE	7	0.26	237	0.17	1398	0.16	33.86	199.71	5.90
TOTAL	2,673	100.00	140,659	100.00	847,461	100.00	52.62	317.04	6.02

Table 3 shows some descriptive statistics concerning publications and citations at the individual level, which are aggregated at the university and regional level.

Table 3. Descriptive statistics on scientific production

Variable	Publications Individual N° TOT	 University N° TOT	 Region N° TOT	Citation Individual N° TOT	 University N° TOT	 Region N° TOT
Total	140,659	140,659	140,659	847,461	847,461	847,461
n° obs	2,673	61	19	2,673	61	19
min	0	4	237	0	10	1,398
max	752	11,259	22,167	5,791	73,525	149,955
mean	53	2,306	7,403	317	13,893	44,603
st. dev	60	2,644	6,262	453	16,894	41,207
mean/st. dev	1.14	1.15	0.85	1.43	1.22	0.92

Each researcher published an average of 53 works, receiving 317 citations. However, individual publications and citations vary between a wide range, since the most productive researcher published 752 works and received 5,791 citations, while the less productive researcher has zero publications and citations. Given this wide range, it is obvious that values for standard deviation are very high for both publications and citations. In both cases standard deviation is higher than mean values, preliminarily showing that the distribution of both publications and citations is very dispersed and asymmetric. The next section will deal precisely with the characteristics of such individual distribution, showing to what extent scientific production is asymmetric, and whether there are differences in such asymmetry when comparing individual distributions by disciplines, universities and academic positions.

3. EMPIRICAL EVIDENCE ON SCIENTIFIC PRODUCTION

The high variability and asymmetry of scientific production is very much clear from Figure 1, which shows at the aggregate level the distribution of the total number of publications and citations across researchers. Figure 1 shows that the distribution of both publications and citations is very much more similar to a Pareto distribution than to a normal one, with very few researchers who are very productive, and a long cue of relatively less productive ones.

Figure 1. The individual distribution of publications and citations

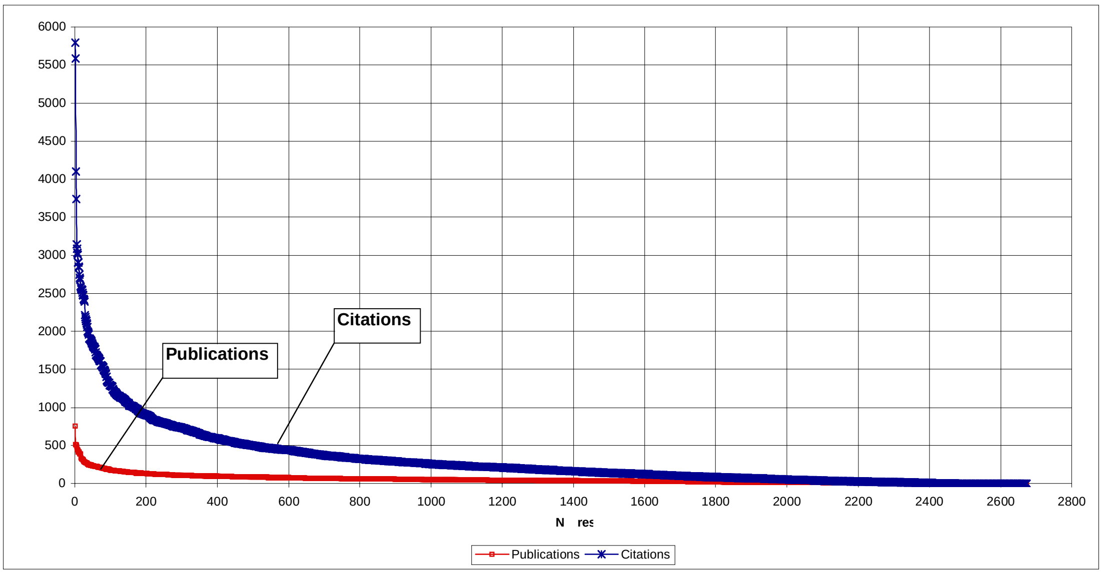
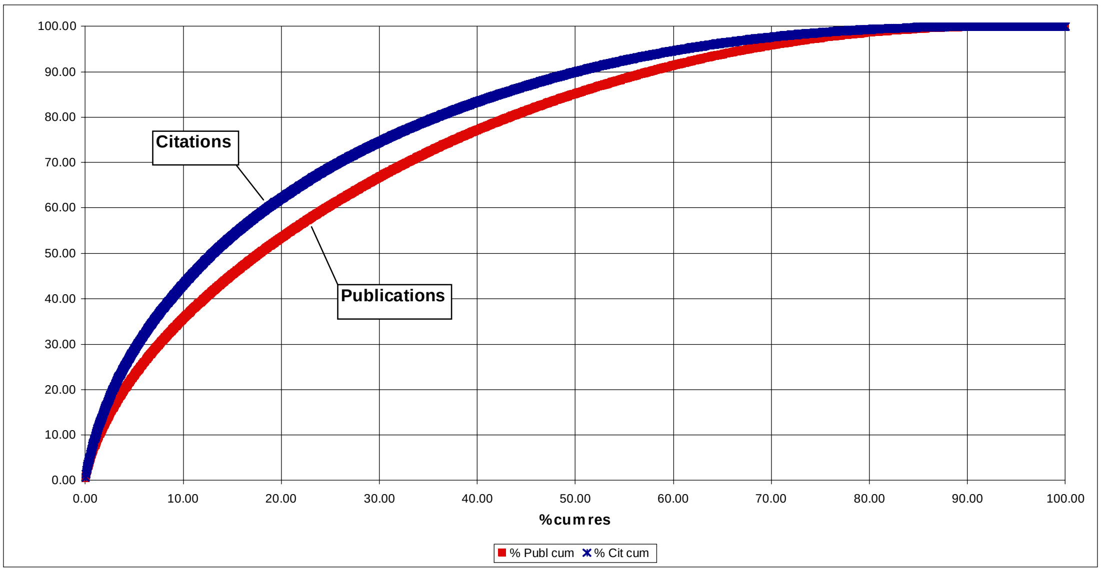


Figure 2 shows the distribution of cumulative publications and citations relating to the cumulative number of researchers. We can see that 20% of researchers concentrate 62.33% of total citations and 54% of publications, confirming the uneven distribution of both publications and citations across researchers.

Figure 2. The individual distribution of publications and citations (cumulated)



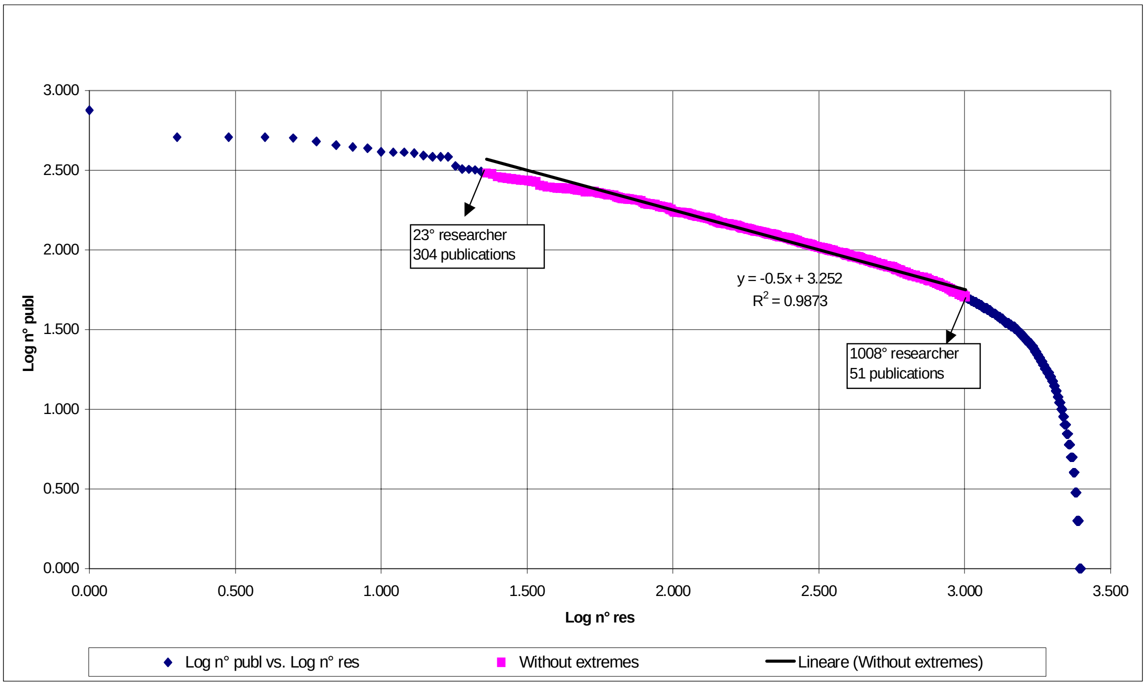
The notion of an uneven distribution of scientific production is very familiar to scholars of economics of science. It has been shown that individual publications, as well as citations, are distributed very asymmetrically across the aggregate population of Italian researchers. Scientific production can be represented quite well by Lotka’s law (Lotka, 1926) where, within an homogeneous group of researchers, the number of publications of a given researcher can be represented as a rapidly decreasing function of the number of researchers, as shown by the following equation:

$$N° \ PUBL_i = k/i^{0,5} \qquad (1)$$

where *k* is the number of publications of the most productive researcher, and *i* is the progressive number of researchers listed by decreasing number of publications.[5] Figure 3 shows the logarithmic distribution of the number of publications according to the logarithm of the researchers. If data is fitted to Lotka’s law, we would have a linear distribution with inclination -0.5.

5 Lotka's law describes the frequency of publication by authors in a given field. It states that the number of authors making n contributions is about $1/n^2$ of those making one; and the proportion of all contributors, that make a single contribution, is about 60 percent. This means that out of all the authors in a given field, 60 percent will have just one publication, and 15 percent will have two publications, 7 percent of authors will have three publications, and so on. According to Lotka's law of scientific productivity, only 6 percent of the authors in a field will produce more than 10 articles. Lotka's law, when applied to large bodies of literature over a fairly long period of time, can be accurate in general, but not statistically exact.

Figure 3. Scientific production and Lotka's law



It is clear that the distribution is not linear in that it decreases less than proportionally before a given threshold (log i = 1.342) and it starts to decrease more than proportionally after a given threshold (namely, after log i = 3.000). The distribution could be considered linear with an inclination of –0.5 only for those researchers between the 23rd and the 1008th researcher.

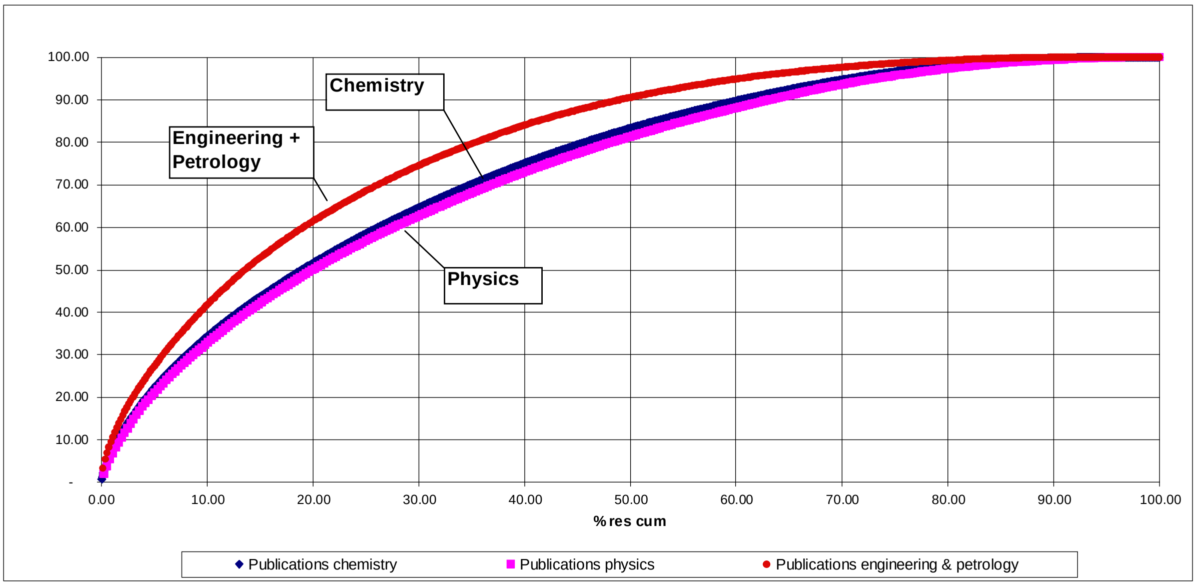
In this context, a deeper analysis that distinguishes between disciplines, universities and the academic positions of the researchers may be useful in order to identify whether there are main differences and specificities in such asymmetric distribution at the discipline, university and academic position levels. The next sub-section will compare the distribution of individual scientific production in terms of disciplines, universities and positions

3.1. The comparison of individual scientific production by discipline, university and academic position

In terms of a comparison across disciplines (Figure 4), a simple analysis of the distribution of cumulated publications shows, firstly, that the distribution in chemistry and physics are much more similar, and actually almost overlapping, than the distribution in engineering and petrology. Since physics is much more a theoretical science, and on the contrary chemistry, engineering and petrology are more applied and technical disciplines, one could have expected different results; namely a more similar distribution between chemistry and engineering.

Secondly, this comparison also shows that the distribution in engineering and petrology is more asymmetric than in physics and chemistry. When comparing the proportions of the more productive researchers (or 'stars') (i.e., those researchers that account for the first 10% of publications) with the proportion of the less productive researchers (i.e., those accounting for the last 10% of publications) across the three disciplines, sectoral specificities arise.

Figure 4. The individual distribution of publications by discipline

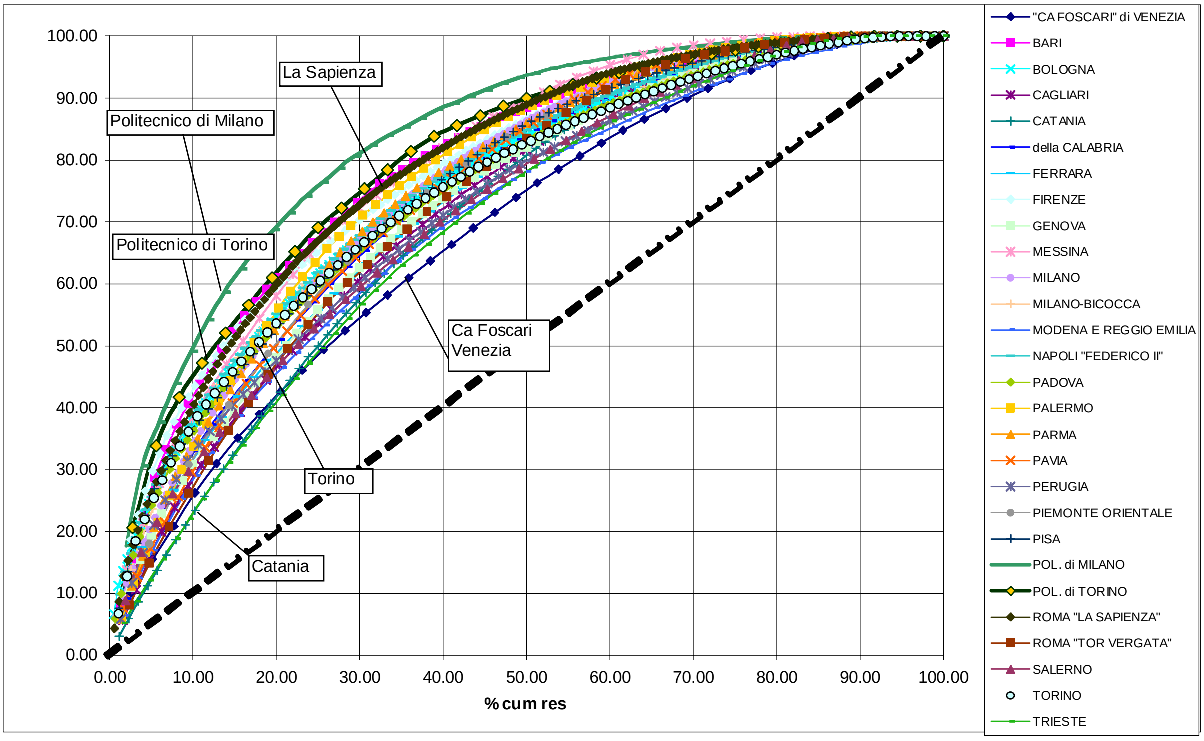


On the one hand, the share of 'stars' is very similar and very small across the three fields. In fact, 1% of the researchers and 2% of the researchers account for the first 10% of publications in engineering, and in physics and chemistry, respectively. Even using a more relaxed criteria for identifying very productive researchers, i.e. considering those researchers who account for the first 20% of publications, the picture doesn't change very much, about 3% and 5% of the researchers accounting for the first 20% of publications in engineering, and chemistry and physics, respectively. On the other hand, the share of the less productive researchers is characterised by a certain degree of variance. If in chemistry and physics this share is quite close (37% in physics and about 40% in chemistry), in engineering and petrology more than a half (51%) of the researchers account for the last 10% of publications. Sectoral specificities in turn account for a variance of about 14% of poorly productive researchers. Such sectoral specificities can be interpreted as differences in the knowledge base characterising the different disciplines, and therefore in the organisation of scientific work and production of knowledge.

These differences in the distribution of individual publications are even higher when comparing the different universities (Figure 5).

Figure 5 shows that, in general terms, the universities in which scientific production is most asymmetric are the two polytechnic schools in Milan, and relatively least asymmetric in Turin. This can be partially due to the fact that the two polytechnic schools are very specialised in engineering, which as Figure 4 showed, is more asymmetric than chemistry and physics. In this sense, there can be a discipline bias explaining why scientific production in polytechnics is more asymmetric. Among the 'generalist' universities, Rome's La Sapienza is the one characterised by the highest level of asymmetry in scientific production. On the contrary, the universities in which scientific production is least asymmetric are the University of Catania and the University of Ca' Foscari in Venice. Between these upper and lower boundaries, there is a wide range of variance especially when considering the share of the less productive researchers.

Figure 5. The individual distribution of publications by university



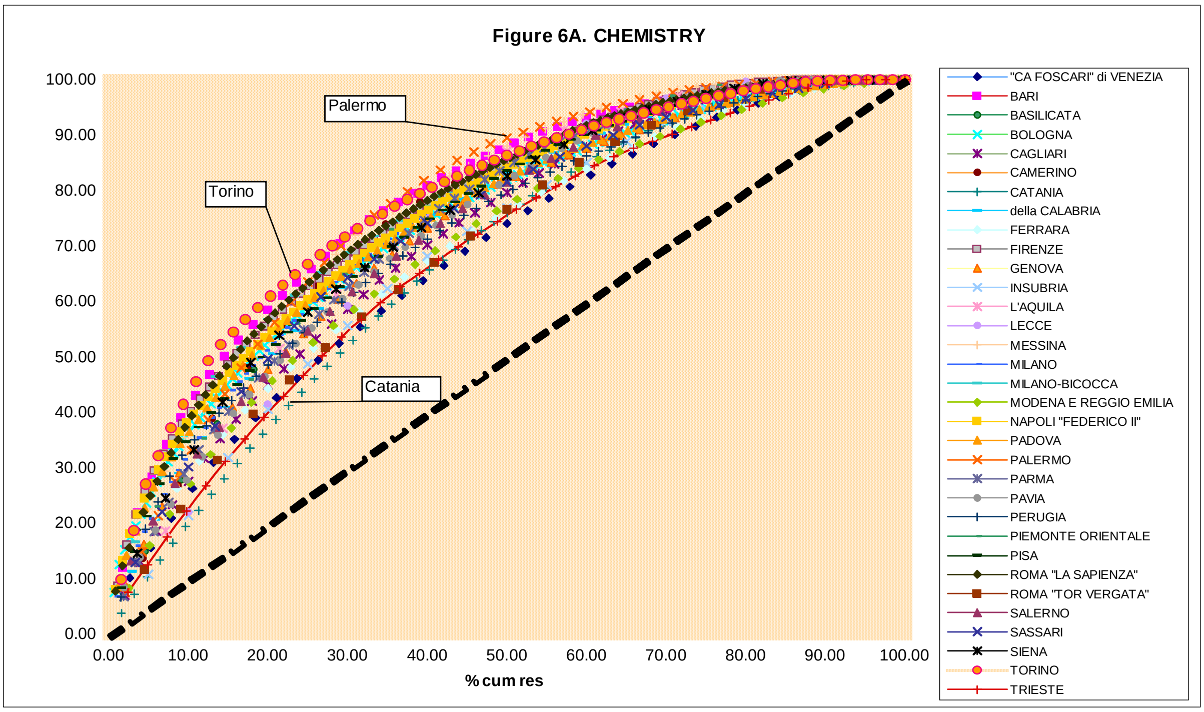
When considering 'stars' and more generally very productive researchers, the differences between universities are, as in the comparison by disciplines, relatively limited. At the 'lower bound' (University of Catania), 4.5% of the researchers account for 10% of the first 10% of publications, and 9% of researchers account for the first 20% of publications. At the 'upper bound' (Polytechnic of Milan), 1% and 4% of the researchers account for the first 10% and 20% of publications respectively. The differences in very productive researchers among universities are in the magnitude of 4-5%. When considering instead the different shares of less productive researchers, the differences between universities are much higher, in that in the university where scientific production is least asymmetric (Ca' Foscari of Venice), 30% of the researchers account for the last 10% of publications, while on the contrary in the Polytechnic of Milan, 57% of the researchers are in the last 10% of publications. Therefore the maximum share of those researchers lagging behind is 57%, while the minimum is 31%: differences across universities account for a variance of almost 30% of the lower levels of scientific production.

The combination of the comparison by discipline and by university (Figures 6A, B, and C) confirms that significant differences in the distribution of scientific production exist at both the discipline and the university level, and that both sectoral and university specificities are relevant to explain the variance between more and less asymmetric scientific productions. For instance, the distribution of scientific publications in the University of Turin is more asymmetric when considering chemistry, while it is less asymmetric when considering engineering and petrology, and it is somehow in between the range of variance across universities when considering physics.

Moreover, and perhaps more importantly, the comparison by university and discipline confirms the fact that the degree of variance across distributions is higher both for 'stars' and very productive researchers, and for less productive researchers, although higher for the less productive researchers than for 'stars' and very productive researchers. The shares of 'stars' and very productive researchers are different across disciplines and universities, and the share of researchers lagging behind varies even more. This may raise a problem of governance in terms of hiring, incentives and monitoring schemes that is relevant at the discipline and university level, and that is most important when considering the risk of 'marginalisation' faced by higher and higher shares of less productive researchers.

The comparison of individual publications by academic position of the single research may be useful in this context, in order to disentangle to what extent asymmetric distributions of scientific production are the result of weaknesses in hiring, incentives or monitoring schemes.

Figures 6(A), (B) and (C). The individual distribution of publications by university and discipline



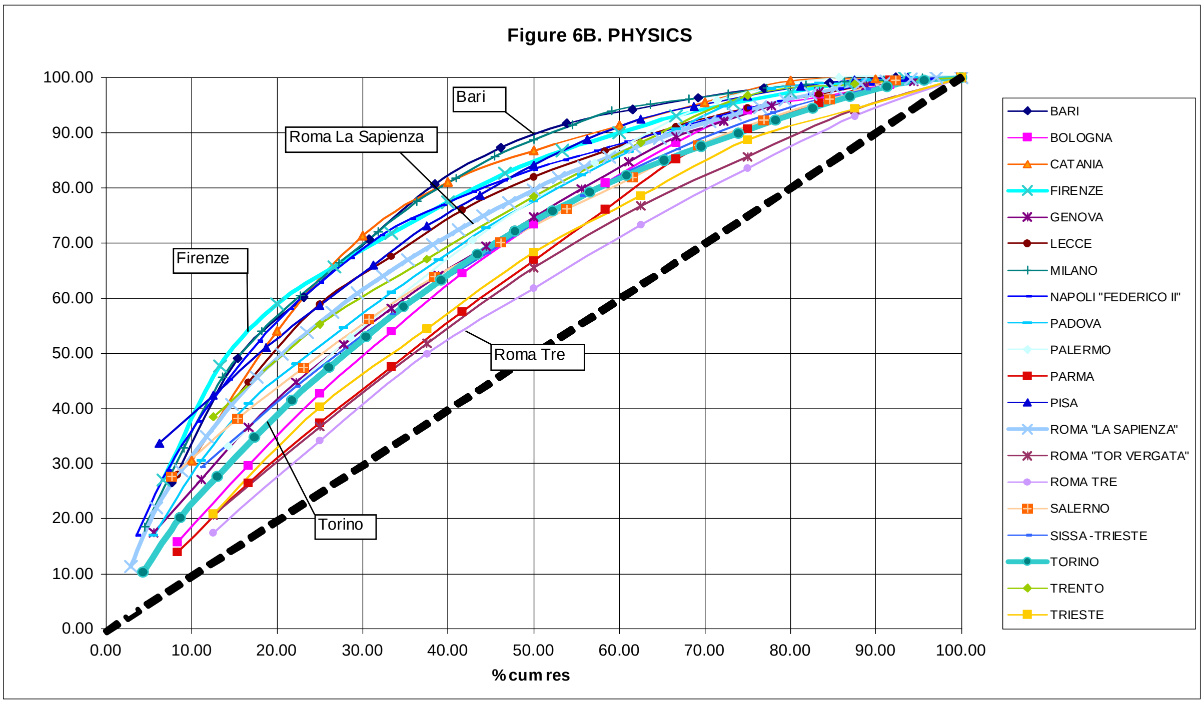
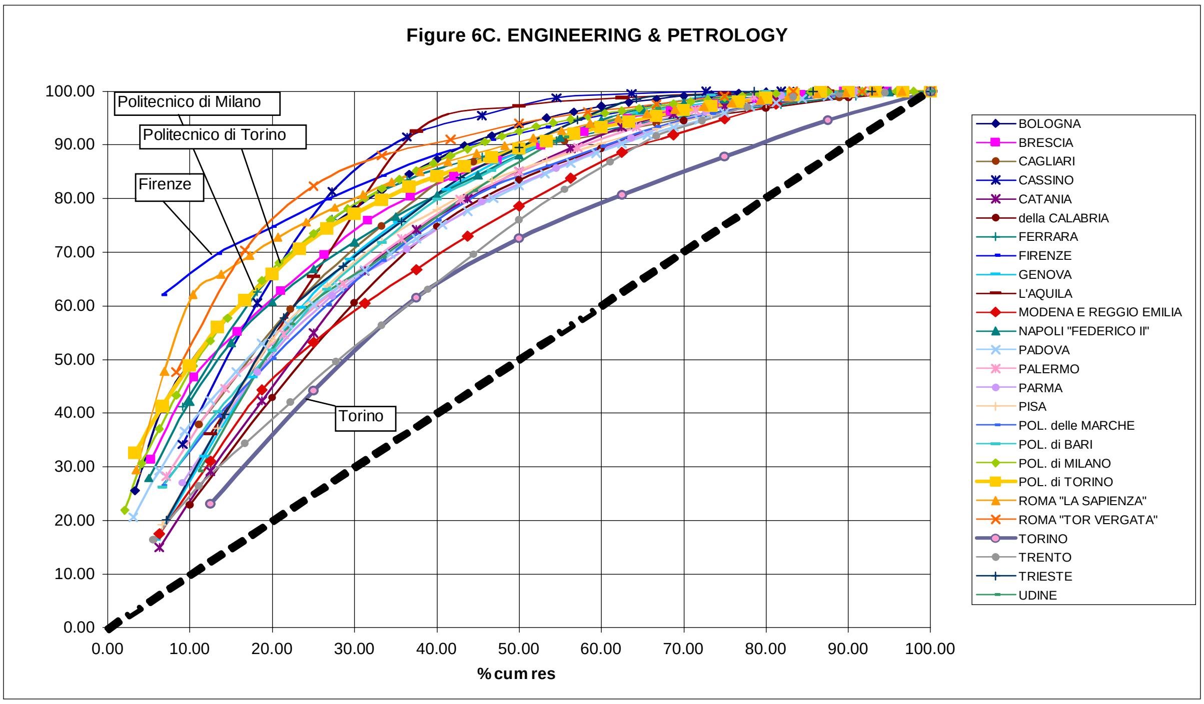


Figure 6 (cont.'d). The individual distribution of publications by university and discipline



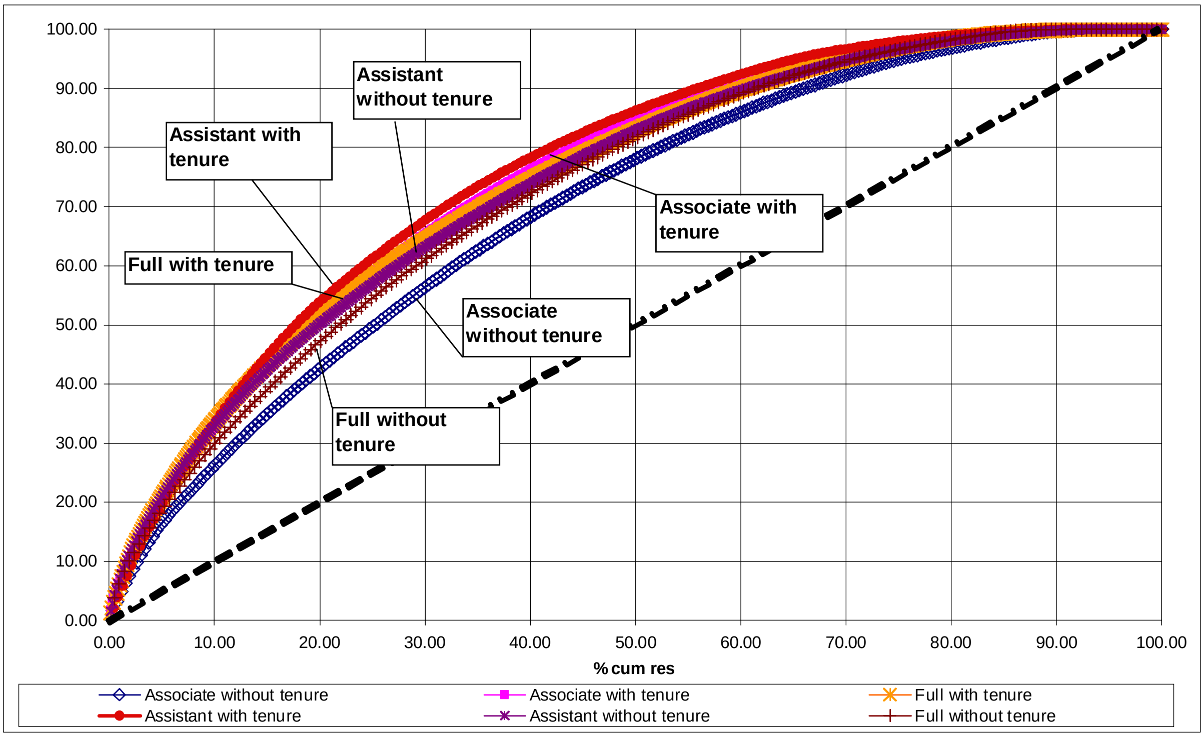
The relative frequency of the different positions (Table 4) by disciplines shows that while in the aggregate sample the different positions are quite proportionally represented, the relative frequency of the different positions varies by field. While assistant professors are generally a smaller category across disciplines, full professors are about 40% and 37% of all the researchers in physics and petrology respectively, while in engineering the larger group is represented by associate professors (37%). Instead in chemistry the distribution of researchers across positions seems more balanced, each category representing about 1/3 of the total researchers.

Table 4. The relative frequency (%) of positions by discipline

Position	Disciplines				*Total*
	Chemistry	Physics	Engineering	Petrology	
Associate professors	34.87	30.34	37.26	31.62	*34.49*
Full professors	34.02	39.04	32.69	36.75	*34.61*
Assistant professors	31.11	30.62	30.05	31.62	*30.90*
Total	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*

Figure 7 compares the distributions of individual publications according to the academic position of the single researchers, specifying between researchers with and without tenure and distinguishing between the following positions: 1) tenured assistant professors; 2) assistant professors without tenure; 3) tenured associate professors; 4) associate professors without tenure; 5) tenured full professors; 6) full professors without tenure.

Figure 7. The distribution of individual publications by academic position



The comparison by academic position confirms that individual publications are asymmetric in general, and also shows that some differences between positions exist (see also Table 5). Firstly, scientific production is less asymmetric when considering associate professors without tenure. On the contrary, assistant professors without tenure are characterised by more asymmetric distribution. The share of stars or very productive researchers shows in fact that 3% of associate professors without tenure account for the first 10% of publications, and 7% of associate professors without tenure account for the first 20% of publications. When considering other positions, about 2% and 4% of researchers account for the first 10% and 20% of publications respectively.

More interestingly, when comparing the share of those researchers lagging behind, 33% of associate professors are lagging behind, against about 45% and 40% of assistant professors without tenure and full professors (with or without tenure) respectively. If the relatively more asymmetric distribution across assistant professors can be explained with an age effect (for younger researchers publishing can be more difficult especially when considering ISI journals), one can argue that the incentive mechanism, i.e. reaching tenure and eventually full professorship, is working better for associate professors without tenure. Considering that the share of tenured associate professors lagging behind is 42%, and that arguably there is no significant difference in terms of age between associate professors with or without tenure, the hypothesis for the relative effectiveness of the incentives mechanism for associate professors without tenure can be put forward.

On the contrary, the relatively high share (40%) of full professors (both with or without tenure) lagging behind can be explained in terms of ‘bad’ incentives and monitoring schemes, inappropriate in ensuring ‘good’ levels of scientific production across researchers. Here the emphasis may be put on the monitoring schemes, rather than on the incentive schemes, at least in terms of advancement in scientific career. Full professors have reached the highest position in the academic carrier, and the governance issue could be monitoring their scientific activity.

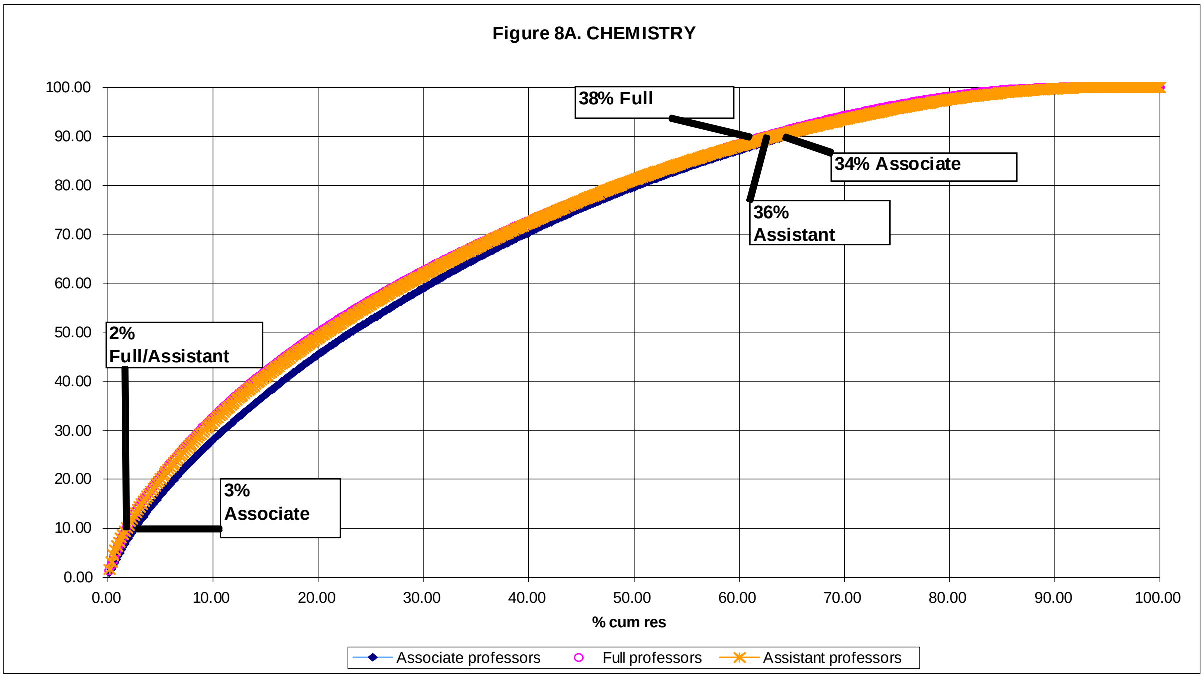
Table 5. The comparison between 'stars' and less productive researchers by academic position

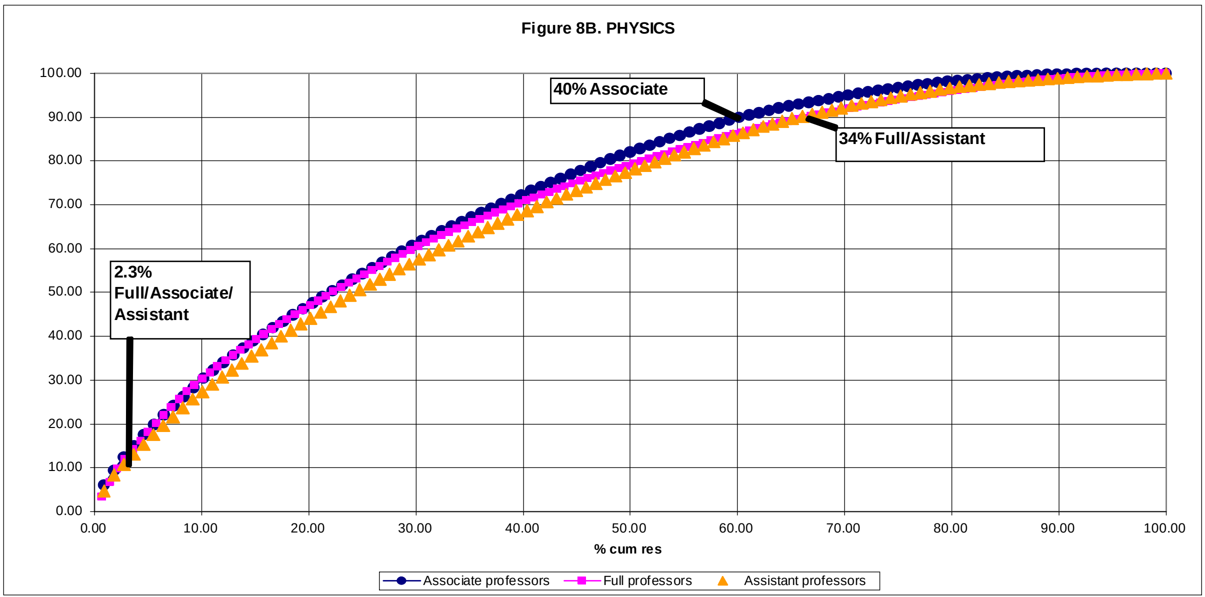
Position	Stars	(%)	Lagging behind	(%)
Tenured Full Professors	13	*1.82*	285	*40*
Full Professors without tenure	4	*1.9*	81	*39*
Associate Professors without tenure	8	*3*	91	*33*
Tenured Associate Professors	12	*1.8*	276	*42*
Assistant Professors without tenure	6	*2.5*	10	*45*
Tenured Assistant Professors	10	*1.69*	233	*40*

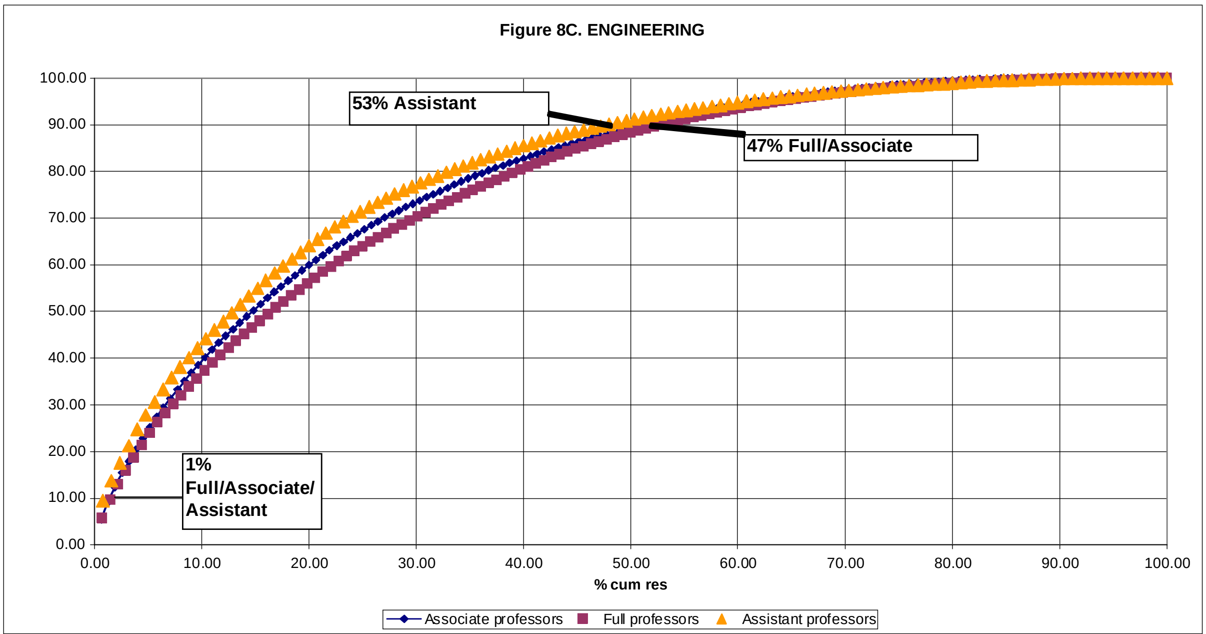
The comparison of the distribution of scientific production by academic position and discipline can be useful in order to show to what extent there are sectoral specificities in the effectiveness of hiring, incentives and monitoring schemes (Figures 8A, B, and C). In all the three disciplines, the share of stars doesn't vary very much across positions and across discipline. About 1-2% of the researchers account for the first 10% of publications, irrespectively of the position and discipline, and little differences arise when considering the first 20% of publications, the share of very productive researchers varying between 4% and 6%. Instead, higher variance characterises the proportions of those researchers lagging behind, showing that the problem of 'marginalisation' is also specific to the academic position of the researchers, and requires specific governance mechanisms.

Moreover, at the discipline level, scientific production in chemistry and physics is relatively less asymmetric across positions than in engineering (although in physics the share of associate professors lagging behind is quite high, 40%, showing that here there can be a problem of incentives for those researchers. This share in chemistry is instead the lowest across disciplines, 34%, thus working better, or being less weak, than in the other fields).

Figures 8(A),(B) and (C). The distribution of scientific production by position and discipline





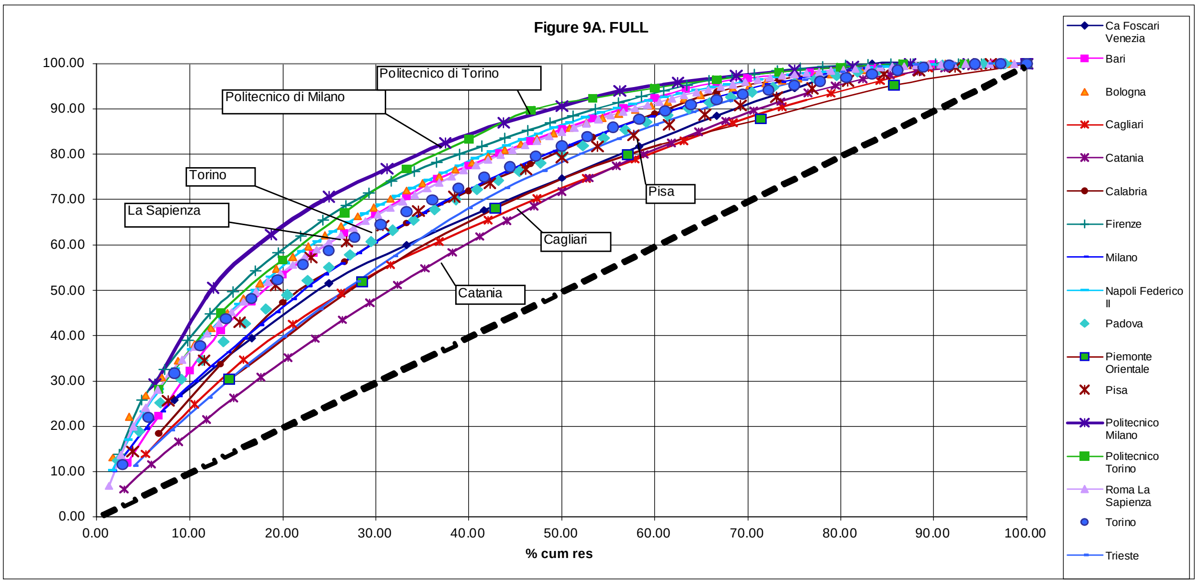


The more interesting results seem to come from engineering. Not only is scientific production in engineering much more asymmetric than in chemistry and physics, but the magnitude of the problem of researchers lagging behind doesn't change so much according to positions. 47% of full and associate professors and 53% of assistant professors are lagging behind and account for the last 10% of publications. A structural problem of governance, specific to the characteristics of the discipline rather than to position, may therefore exist. The organisation of scientific activity in an Italian university can be described as too individualistic, facing the risk of a high level of marginalisation for the researchers in those disciplines, such as engineering, that require models of governance more focused upon teamwork, collective research and joint projects. Sectoral characteristics matter and require specific governance models.

Finally, the comparison of the distribution of scientific production by university and position (Figures 9A, B and C) confirms that university specificities matter when considering both stars and very productive researchers, and those researchers lagging behind. A high variance exists across universities and at all positions, showing that the quality of the hiring, incentives and monitoring schemes is also specific to the single universities.

For instance, when considering assistant professors lagging behind, at the lower bound (the university of Ca' Foscari in Venice), only 20% of the researchers account for the last 10% of publications. On the opposite side, in the Polytechnic of Milan, about 60% of assistant professors are in the last 10% of publications. Similarly, considering full professors in the University of Cagliari, 26% of researchers account for the last 10% of publications, while in the Polytechnic of Turin, 54% of full professors are lagging behind. Finally, 58% of associate professors in the Polytechnic of Turin are lagging behind, against 30% of less productive researchers in the university of Ca' Foscari in Venice. In this context, the fact that the two polytechnic schools in Turin and Milan are characterised by a very asymmetric distribution, may be affected also by discipline specificities, and more precisely, by the very asymmetric nature of scientific production in the engineering field.

Figures 9(A), (B) and (C). The distribution of publications by university and academic position



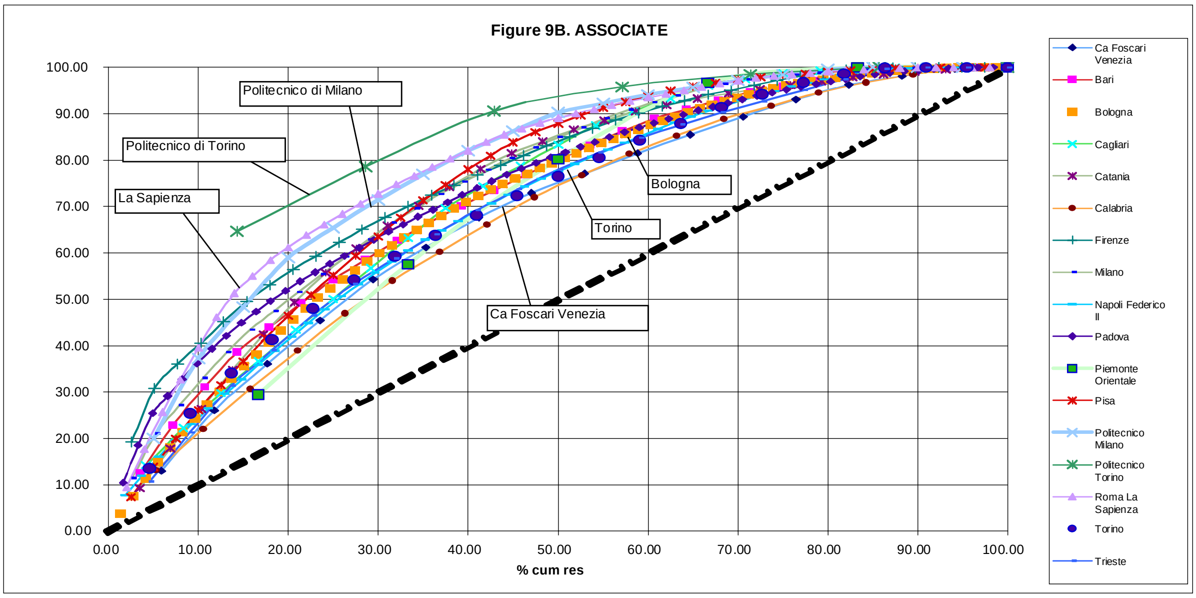
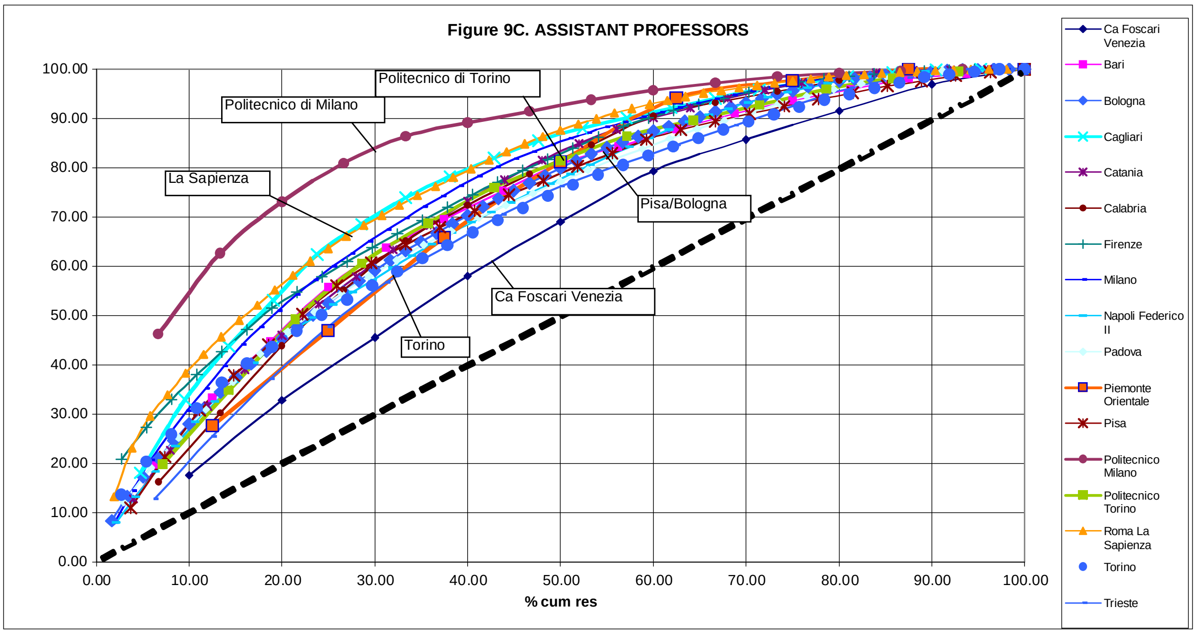


Figure 9(C): The distribution of publications by university and academic position



However, at the university level it is clear that the variance can be affected by at least two factors: 1) the scale of the university and the number of researchers by position, and 2) the number of publications generated by the most productive researcher in each position in the single universities. In other words, less asymmetric distribution may be also the result of a lower average quality of scientific research in the single universities, and by position. Future research should also account for this effect.

In sum, the descriptive evidence of the distribution of scientific production by discipline, position and university, shows that the asymmetry of publication is characterised by a relatively high level of variance according to the scientific field, the academic position held by the researchers, and the university in which the researchers are active. Such specificities can be relevant when trying to provide an interpretative framework that puts emphasis on the weaknesses of the models that govern scientific activity, especially in terms of hiring, incentives and monitoring schemes.

The next section will try to put forward such an interpretative framework, representing also the basis for a research agenda both on the characteristics of scientific production, on organisation, and on its governance implications.

Table 6 compares the distribution of stars, very productive researchers and researchers lagging behind at the aggregate, discipline, university and position level, where stars are defined as those researchers who account for the first 10% of publications, very productive researchers as those who account for the first 20% of publications, and the less productive researchers are those accounting for the last 10% of publications. The universities of Ca' Foscari in Venice, Rome's La Sapienza and Turin are taken as a 'sample' of the whole population since they represent, respectively, the lower and upper bounds (i.e., those universities in which scientific production is relatively less and relatively more asymmetric), and a sort of average distribution, in between the lower and upper boundaries.

The picture described in Table 6 synthesises the fact that, given the aggregate distribution, some interesting differences exist both between the specific (discipline, universities, and positions) levels and the aggregate one, as well as within each level. If the share of 'stars' doesn't vary very much (though at the position level some differences exist), and it is very small across levels, the share of very productive researchers and, especially, the share of those researchers who are lagging behind in scientific publications are characterised by higher levels of variance. Such a variance can in a preliminary way suggest that different disciplines, universities and positions imply different modes of scientific production, different organisations of scientific labour and therefore different governance models.

Table 6. Stars, very productive researchers and researchers lagging behind at the aggregate, discipline, and position level (cumulated percent)

	% of publications (cumulated)		
% researchers (cumulated)	1st 10%	1st 20%	last 10%
Total aggregate	1%	4%	42.5%
Engineering	1%	3%	51%
Physics	2%	4.8%	36.5%
Chemistry	2%	4.3%	39%
Ca Foscari Venezia	2.5%	7.5%	30%
Torino	2%	4%	37%
Roma La Sapienza	1.5%	3.4%	48%
Tenured Full Professors	1.82%	4.75%	40%
Full Professor without tenure	1.9%	5.5%	39%
Associate Professors without tenure	3%	7%	33%
Tenured Associate professors	1.83%	5%	42%
Assistant Professors without tenure	2.5%	5%	45%
Tenured Assistant Professors	1.69%	4.50%	40%

3.2. Scientific activity and R&D expenditures

In order to capture the effect of positive externalities stemming from R&D investments to scientific activity, this sub-section correlates the amount of R&D expenditures at the regional level to the amount of publications in each region (see Table 7).

Table 7. Publications and R&D expenditures in Italian regions (average value 1990-2001; .000 Euros; constant prices 1995)

Region	N° pubblications	R&D tot	R&D private	R&D public
EMILIA-ROMAGNA	22,167.00	711,752.58	379,880.17	331,872.67
LOMBARDIA	18,634.00	2,329,485.25	1,808,760.58	520,724.58
TOSCANA	15,513.00	558,687.58	206,042.25	352,645.25
LAZIO	13,229.00	1,904,128.17	606,956.08	1,297,171.75
CAMPANIA	11,050.00	500,306.83	191,737.92	308,569.00
VENETO	9,483.00	423,185.33	213,965.83	209,219.25
PIEMONTE	9,143.00	1,567,384.17	1,367,001.75	200,382.25
SICILIA	7,748.00	311,484.67	59,695.00	251,789.50
PUGLIA	5,460.00	205,285.08	68,893.08	136,392.25
FRIULI	5,436.00	222,353.50	119,898.08	102,455.42
UMBRIA	4,823.00	84,283.17	17,613.50	66,669.92
SARDEGNA	4,351.00	117,888.08	17,461.33	100,426.75
LIGURIA	3,621.00	332,267.25	166,293.00	165,974.17
MARCHE	3,396.00	96,425.67	31,421.08	65,004.17
CALABRIA	2,116.00	49,656.25	4,463.67	45,333.92
TRENTINO-ALTO ADIGE	1,709.00	75,325.58	31,990.83	43,334.50
ABRUZZO	1,656.00	150,082.92	84,504.83	65,578.00
BASILICATA	887.00	37,495.42	9,772.33	27,723.08
MOLISE	237.00	10,239.17	2,067.00	8,171.92

The results of the correlation (Figures 10A, B, and C) shows that the correlation is positive and significant when considering either total R&D, private R&D and public R&D.

Figure 10A. Correlation between publications and total R&D expenditures

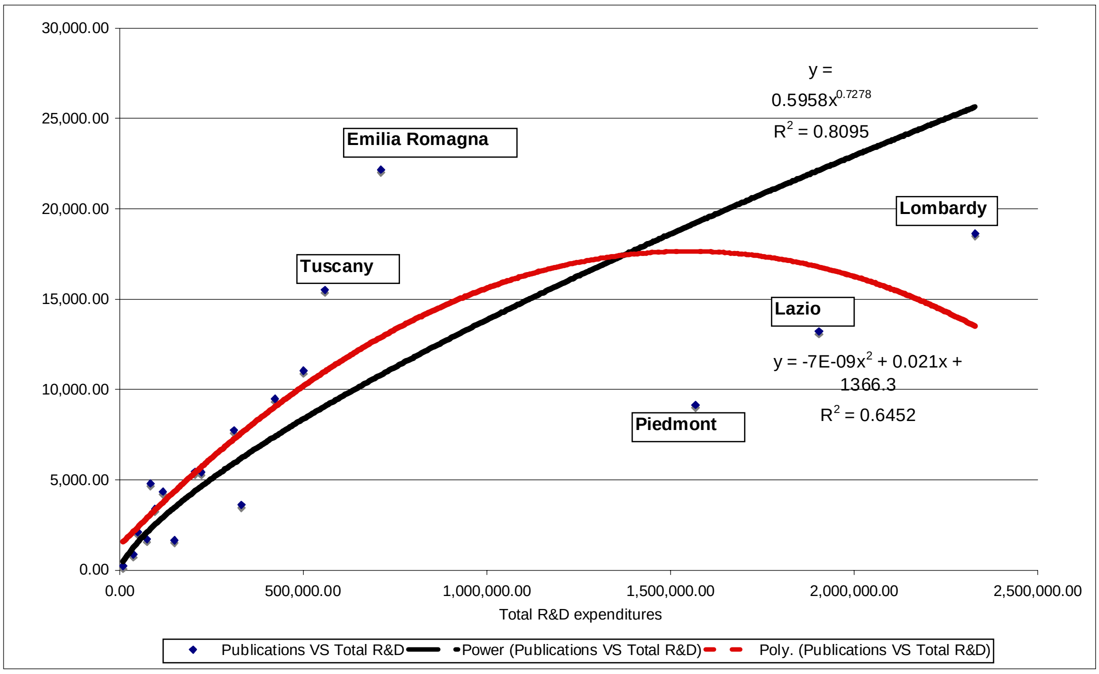


Figure 10B. Correlation between publications and private R&D expenditures

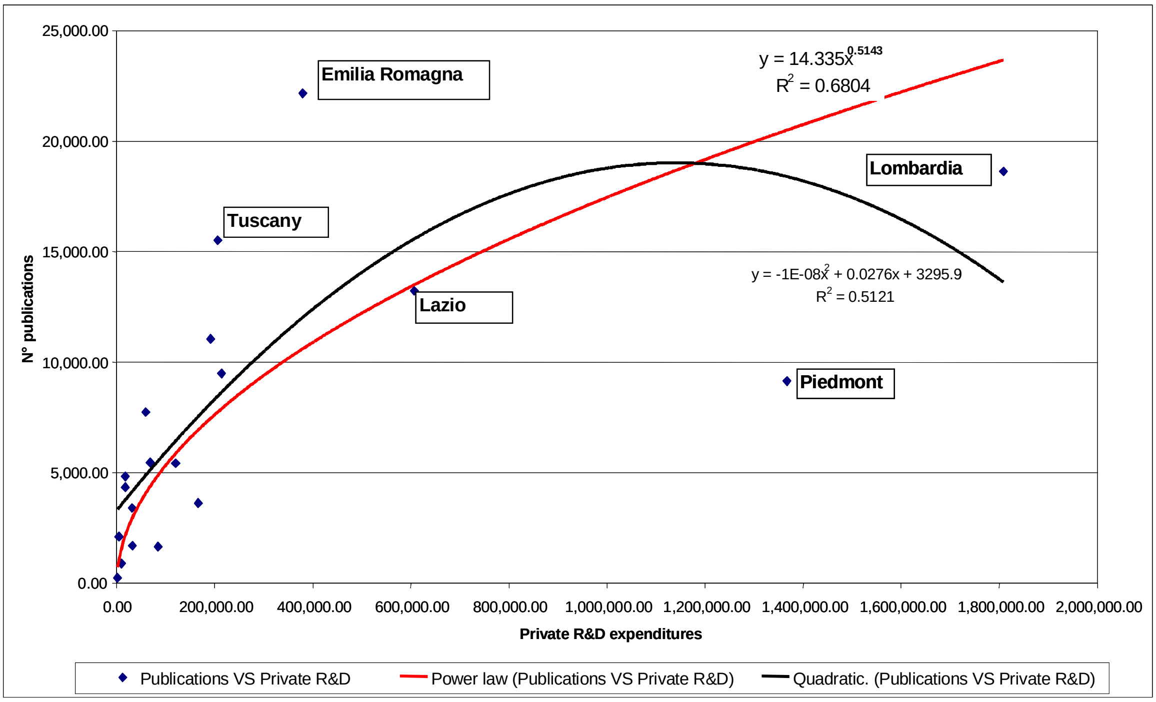
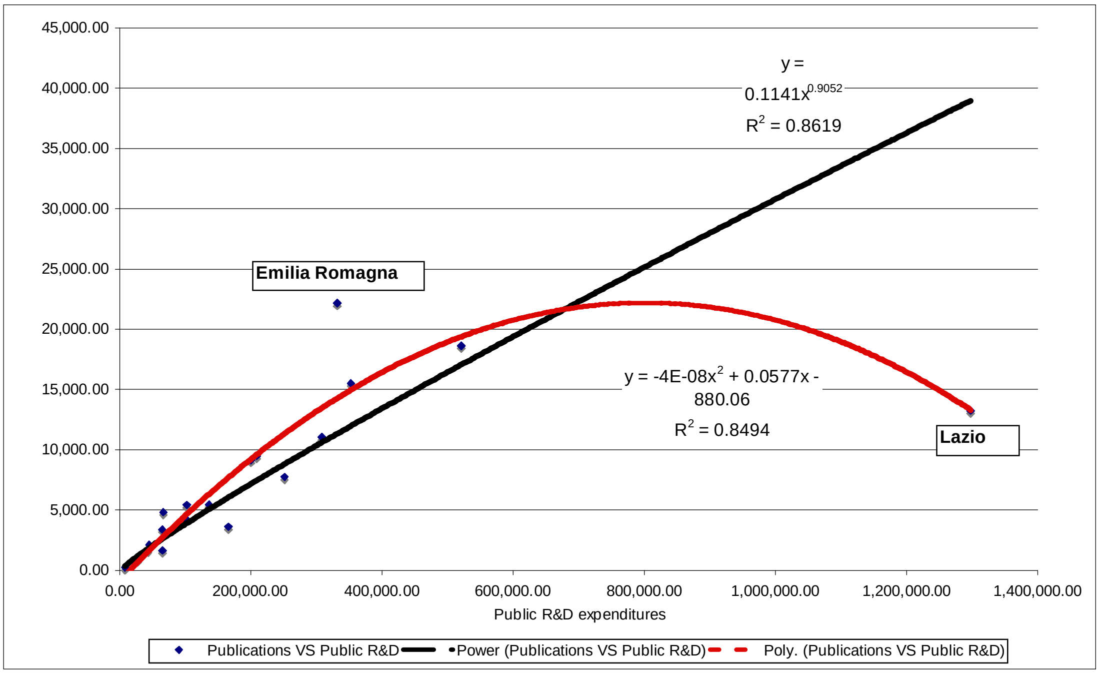


Figure 10C. Correlation between publications and public R&D expenditures



However, publications increase less than proportionally with respect to R&D expenditure, since the exponent of the power law that represents the correlation is < 1 for either total R&D, private R&D and public R&D (precisely, 0.7278, 0.5143 and 0.9052, respectively).

This shows that the role of positive externalities from R&D to science is limited and that the concentration of high level of R&D expenditures generates benefits for scientific activity only to a minor extent. More precisely, positive effects are relevant only under a given threshold, that is, for smaller (in terms of both publication and R&D investments) regions (those regions located in the bottom-left corner of the space). On the contrary, the case of Piedmont and Lazio (and even Lombardy), which are the three largest regions in terms of R&D expenditure, show that the output in terms of publications is by far less than proportionate with respect to R&D investment. On the contrary, we can identify only two "good" models in which scientific production benefits from R&D investments, that is, in which scientific production is more than proportionate to R&D expenditures, namely Emilia Romagna and Tuscany.

These results are particularly striking when considering total R&D investments, and are reinforced when considering private R&D expenditures (coefficient = 0.5143).

These results open the room for questioning science policy aiming at the concentration of resources in given spaces, in order to benefit from externalities between the R&D and academic systems. Our results show that high concentrations of R&D expenditures do not favour higher performance in terms of scientific publications.

4. INTERPRETATIVE FRAMEWORK AND RESEARCH AGENDA

Our results, based on simple statistics, show that the extent to which the distribution of scientific production is more or less asymmetric largely varies according to discipline, university and academic position. How can these differences be explained?

Firstly, at the discipline level, a new perspective can be useful in understanding the relationship between sectoral characteristics and scientific production. One that puts at the centre of the analysis the specific knowledge base of scientific fields, and that relates such a knowledge base to the specific pattern of learning, organisation of scientific work, and communication that characterise scientific fields. According to the characteristics of the knowledge base of different scientific fields, patterns and norms of learning, organisation and communication emerge here as relevant.

The analysis developed by Michael Polanyi (1958 and 1966) and by Cowan, David and Foray (2000) on the different characteristics of knowledge can be useful to understand 1) the way in which different knowledge bases require different learning and communication patterns, and 2) the way in which such learning and communication norms imply different organisations of scientific labour.

On the one hand, when more tacit and technology-oriented sciences are considered (such as engineering), teamwork can be important because of the different communication patterns required. In this case knowledge is not public and relying on a pure scientific base, but is much more the result of the implicit accumulation of experience, routines, learning by doing and learning by interacting. However, when knowledge is tacit, scientific norms, methodology and techniques are only locally shared within small communities working on the same technical problem through idiosyncratic learning and communication practices. Engineering can be described as a synthetic work, based on the interaction and integration of different pieces of knowledge in order to solve complex problems. The integration of such different portions of knowledge, and their translation into a common language, may therefore be difficult. In this context, face-to-face communication and learning by interacting are a most important practice in the organisation of research activities. Because such a knowledge base is mainly personal, even when it is shared within a community vis-à-vis interactions, master-apprentice-like relations, and learning on the task are the typical modes of learning and communication of that knowledge and hence of definition of a new scientific output (Polanyi, 1958 and 1966). In this context, good monitoring and incentives schemes, especially when focused on favouring interactions and the formation of research groups and collective projects, may be more important than hiring schemes.

On the contrary, more codified sciences such as physics can be characterised by spatially widespread learning and communication patterns, and by a more individualistic organisation of scientific work. According to the analysis developed by Cowan, David and Foray (2000), when knowledge is mainly codified, a specific "codebook" defining the methodological and technical specifications of a given scientific output exists. The members of the scientific community systematically and explicitly refer to that codebook when generating scientific outputs, which are codified to a great extent. In this case, the knowledge base underpinning the generation of science is public to a greater extent, and acquisition and distribution occur mostly by means of so-called 'blueprints'. The codified character of their knowledge base allows scientists to potentially share the same language, and learn scientific methodology and techniques widely, in part independently from the team and the academic context in which they are working. In this perspective, the individual characteristics of the single researcher (such as creativity, technical competence, the ability to find important research questions and persistence) may be more important than teamwork. Good hiring schemes may be more relevant than monitoring and incentives activities.

Located somewhere between tacit and codified knowledge, articulable knowledge presupposes some degree of codification. Nevertheless, the codebook that establishes the definitions of such knowledge, and the procedures for its implementation into a given scientific output, is not manifest even to the members of the community which finally employs the knowledge and develops the scientific output itself. Even though an explicit book of definitions and instructions exists, it is not explicitly consulted and the contents of the codebook have been so fully internalised and appropriated within the community that they operate as implicit sources of technical knowledge and procedural rules. Articulation being social communication, the degree to which articulable knowledge is public or private, and hence the extent to which it is shared within the social and scientific community, depends on the costs of access, transmission and absorption of the relevant technical specifications and implementation procedures (Cowan, David and Foray, 2000). This can be the case of chemistry, typically an applied science, where learning and communication patterns, and the role of teamwork, can have a varying importance according to the specific field. From the governance viewpoint, the appropriate mix in terms of hiring, monitoring and incentives schemes should take into account such field specificities.

Secondly, considering the academic position, our evidence shows that differences exist across positions, especially when combined with a consideration of discipline specificities. Appropriate governance of science should take into account these specificities, implementing localised and specific mechanisms and schemes, according to the specific characteristics of the category of researchers and the discipline considered. In this regard, governance mechanisms aiming to reduce the marginalisation of assistant professors (i.e. reducing the number of less productive assistant professors) should focus on appropriate hiring criteria and upgrading programs. At the same time, governance mechanisms aimed at ensuring less asymmetric scientific production for associate and full professors, should instead be focused on the implementation of appropriate incentives and monitoring procedures.[6] However, such governance models cannot take sectoral differences for granted. For instance, hiring, incentives and monitoring mechanisms to ensure 'good' scientific production in engineering, should focus upon the collective nature of scientific work in the field, rather than encouraging individualistic behaviour that may lead to a high level of marginalisation of relatively less productive researchers, of the kind that we observed in our evidence. Here an appropriate science policy could be, for instance, based on the implementation of a network of researchers, as well as joint project and multidisciplinary collaborations.

Thirdly, at the university level, the combination of sectoral and positional specificities can be relevant. The high variance in terms of asymmetry of the distribution of publications across disciplines and positions between the different universities, also demonstrates that local governance systems vary according to scientific field and the position of the researcher. In some cases governance can be weak, when considering the effectiveness of hiring and upgrading mechanisms for assistant professors in chemistry, in other cases it can be weaker in monitoring full professors' activity in physics. In this context it is clear that the specialisation of single universities in given fields, but also in given positions (i.e., the relative share of full, associate and assistant professors in the different universities) does matter. At the same time, the level of scientific publications, and more precisely the level of scientific publications for the most productive researchers, also matter in this context. In other words, the distribution of scientific production in a given university may be less asymmetric than in others, simply because on average the researchers there publish less than researchers in other universities.

Finally, considering the relationship between R&D expenditure and scientific publications at the regional level, science policies supporting the concentration of a high amount of resources in a given space, in order to take advantage of the externalities between R&D and science, could be called into question by this research. The positive effects from R&D investments to scientific publications exist only under a certain threshold, and when considering regions characterised by large R&D investments, some of these benefits disappear. The system of incentives and the rationales for science may differ from those in the R&D system and the next steps of this research should investigate this issue.

6 Obviously monitoring and incentives issue are relevant also for young assistant professors, and upgrading should be relevant also for associate and full professors. What I want to stress here is the emphasis on specific mechanisms that are crucial for the different academic positions, or at least relevant for the Italian academic system. Hiring a 'bad' assistant professor or failing in providing the appropriate upgrading programs for a 'good' young assistant professor, will lead to the progressive marginalisation of the researcher, who will become an inefficient researcher in the system. Thus hiring, upgrading or training are crucial for assistant professors. On the contrary, it is clear that the hiring issue is not relevant anymore for associate and full professors.

5. CONCLUSIONS

The simple and descriptive evidence presented in this paper confirms that the distribution of scientific production is very much asymmetric. Moreover, it shows that significant differences emerge in such a distribution when comparing scientific production across disciplines, universities and academic positions. A relevant degree of variance across distributions exists when comparing scientific production at the sectoral, university and position level. These differences can be interpreted in terms of sectoral, university and positional specificities, as well as the way in which scientific activities are organised and governed. In particular, sectoral specificities seem to be quite strong in terms of the way in which researchers learn and upgrade their competences, organise and implement their research activity, and are stimulated to publish by different governance schemes. For instance, high levels of marginalisation in technical sciences such as engineering and petrology), can be explained in terms of a lack of incentives to organise collective research activities and to implement teamwork and collaborative projects that are crucial for the discipline. Engineering is very much a synthetic science based on the integration of and interaction between different competences necessary to solve complex technical problems. Individualistic organisation of work and individualistic incentives may be inappropriate, explaining the very asymmetric nature of scientific production in the field. Finally, positional specificities also seem important in order to put forward appropriate governance schemes. Assistant, associate and full professors may be stimulated to achieve 'good' levels of scientific production by different means. When considering the differences in terms of individual distribution of scientific production across positions, good hiring and upgrading mechanisms may matter less in the case of young assistant professors, while on the contrary effective incentives and monitoring schemes can be more relevant with regard to associate and full professors.

A variety of localised models of science governance can be relevant when considering the differences in terms of scientific production across disciplines, universities and positions. Generalist governance models may be inappropriate to sustain high quality and less asymmetric levels of scientific production, since they do not take into account such differences. Models of governance must be localised according to discipline, university and position specificities. The articulation of such governance models can be very important in the understanding and implementation of science policy, and will be one of the next steps of this research project. Obviously, such an articulation should be based on deeper evidence of the characteristics of scientific production at the discipline, university and position levels. In particular, the following issues can be very important and should be taken into account in the next steps of the research.

Firstly, the analysis of the characteristics and organisation of science in the different disciplines can be most relevant in explaining differences in scientific production and deserves a deeper analysis. For instance, the initial assumption by which chemistry can be understood as an applied science, more similar to technical sciences such as engineering and petrology rather than to theoretical sciences such as physics, does not seem correct. The distributions of scientific production in chemistry and engineering are more similar to each other and quite distinct from technical fields. In this respect the nature and organisation of scientific activity in the different types of science needs to be qualified carefully, through qualitative and historical analysis.

Moreover, the differences across disciplines in terms of the knowledge base (tacit, codified, articulable) behind scientific fields needs to be integrated with the analysis of other factors and cognitive characteristics that may be important to understand the different structure and organisation of scientific production in different disciplines. For instance, some of the differences between the disciplines could be due to differences in the definition of what is considered as important output. Engineers may view publication as less important than theoretical physicists do. In this perspective, ISI publications may be a less appropriate measure for scientific production in engineering than they are in the natural sciences.

Furthermore, engineers may also have different career aspirations, which could make them more mobile (less likely to stay in the academic environment) and more prone to external and consulting activity, in turn devoting less time and smaller resources for 'true' scientific research and publications. Differences between disciplines in terms of the number of years individuals worked in academia may exist, and explain differences in scientific productivity.

Finally, the next steps of this research project should also account for:

1. The existence of scale effects, in terms of both the number of researchers and R&D expenditures, in scientific production at the discipline and university level
2. The effect of local specialisation (university level) in terms of sectoral scientific production
3. The differences, in terms of scientific production and its asymmetry, across universities in terms of both the shares of the different researchers (e.g., are there universities in which assistant professors are over dimensioned with respect to associate and full professors? How does this relate to asymmetric distribution of scientific production?), and the value of publications (i.e., what is the relationship between different levels of scientific production and asymmetry in the distribution of publications?).

REFERENCES

Cowan, R., David, P. A. and Foray, D. (2000) 'The explicit economics of knowledge codification and tacitness', *Industrial and Corporate Change* 9 (2), 211-253.

CRUI – Conferenza dei Rettori delle Università Italiane (2002) 'La Ricerca Scientifica nelle Università Italiane: Una Prima Analisi della Banca Dati ISI', CRUI: Rome.

Dasgupta, P, and David, P. (1994) 'Towards a new economics of science', *Research Policy* 23 (59, 487-521.

Lotka, A. J. (1926) 'The frequency distribution of scientific productivity', *Journal of the Washington Academy of Sciences*, 16(12):317-323.

Katz, J. S. (1999) 'The self-similar science', *Research Policy* 28 (5), 501-518.

Polanyi, M. (1958) *Personal Knowledge. Towards a Post-critical Philosophy*, London: Routledge & Kegan Paul.

Polanyi, M. (1966) *The Tacit Dimension*, London: Routledge & Kegan Paul..

Senker, J. (1995) 'Tacit knowledge and models of innovation', *Industrial and Corporate Change* 4, 143-151.

Zucker, L. G., Darby, M. R. and Brewer, M. B. (1998) 'Intellectual human capital and the birth of US biotechnology enterprises', *American Economic Review*, 88 (11), 290-306.

Pier Paolo Patrucco
Department of Economics
University of Turin
Via Po 53
10124 Turin, Italy
pierpaolo.patrucco@unito.it