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Research Policy 33 (2004) 1081–1102
research policy
www.elsevier.com/locate/econbase

Does research organization influence academic production? Laboratory level evidence from a large European university

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Received 31 July 2003; accepted 31 March 2004
Available online 30 July 2004

Abstract

The paper analyses scientific research production at the laboratory level. The evidence on which the study is based describes precisely the research activity over the period 1993–2000 of more than eighty labs belonging to Louis Pasteur University, a large and well-ranked European research university. The research organization of the labs is analysed by focusing on the characteristics of the research personnel in relation with the scores in two outcomes that are publications and patents. The paper proposes a five-classes typology of laboratories that highlights different styles of research organization and productivity at the laboratory level. It also studies the determinants of the publication performances of labs. We show how appropriate combinations of inputs in academic labs may be strongly associated to high publication performances. We find that combining full-time researchers and university professors in labs tend to preserve incentives. Highly publishing labs also patent. The size of the labs, the individual promotions, and the role of non-permanent researchers and of non-researchers are also underlined.

JEL classification: L31; 031; 032; 034; 038

Keywords: Economics of science; Academic research laboratory; Organization; Typology

1. Introduction

The individual researcher is usually the standard level for analysing academic research production. Most studies concentrate on the effects of individual determinants of academic productivity such as age (Zuckerman and Merton, 1972; Diamond, 1986; Stephan and Levin, 1997), cohort (Weiss and Lillard, 1982), training (Garcia-Romero and Modrego, 2001) and gender (Stephan, 1998). Nevertheless, Stephan (1996) recently highlighted that such studies have a weak ability to explain research productivity, due to the collective nature of research. Thus, some scholars suggest that further investigation of academic research production should take into account some collective level of organization, such as (specifically in the institutional European context) the laboratory level (Dasgupta and David, 1994; Stephan and Levin, 1997). Such a consideration is congruent with even more recent analysis, evidencing that the quality of other researchers belonging to the laboratory is a crucial variable for explaining individual productivity[1]

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[1] These results are grounded in initial evidencing of the Matthew effect (accumulative advantages in science) by Merton (1968), first discussed in economics by David (1994). Carayol (2003a) intro-

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doi:10.1016/j.respol.2004.03.004

(Mairesse and Turner, 2002). Nevertheless, it is one thing to assess collective effects on individual productivity and it is another to change the level of analysis as the results of Adams and Griliches (1998) demonstrate[2]. The results at a collective level may be quite different from the individual researcher especially due to important externalities among researchers within labs: Critical knowledge spillovers, reputation, sharing of equipment instrumentation and facilities, complementarities between different types of researchers, or even between different research agendas.

While most of the literature focuses on the determinants of individual productivity or of the productivity of universities or groups of universities, few contributions analyse the academic production at the laboratory or team level. Such a concern brings into the scope papers more interested in organization and managerial issues, which tend to show that the laboratory is indeed a critical level of organization. Crow and Bozeman (1987) show that laboratory funding structure is strongly correlated with the nature of the research realized, Joly and Mangematin (1996) illustrated various types of contracting and laboratory strategies and Laredo and Mustar (2000) developed a technique for stressing "laboratories activity profiles" according to five dimensions (production of certified knowledge, education and training, research and innovation, involvement in the construction of public goods, and participation in public debates). Arora et al. (1998) studying academic research at the laboratory (or team) level showed that (even if relying on cross-section data) there are decreasing returns of funding on "quality adjusted" publication while the most reputed teams reveal an elasticity of scientific performance with respect to funding which approaches unity. Bonaccorsi and Daraio (2002) showed that the distributions of the average age of scientists in the labs and the size of the labs are correlated. In three out of six domains, they found that the size of the labs (i.e. the number of researchers) is negatively correlated with productivity.

duced a model of such dynamically biased competition grounded on the difference among the inherent productivity of research positions in different universities.

[2] They showed that university departments exhibit decreasing returns to scale at the university departments level of analysis while the whole system of universities exhibits constant returns to scale.

Even if these studies improve considerably our understanding of academic knowledge production, there are still many unknowns to reach a robust industrial organization theory of academic research production. Such an aim certainly lies beyond the scope of this paper, the purpose of which is to improve our understanding of how laboratories differ in organizational terms, in outcomes and how organization is related to productivity. By organization we mean the composition of research laboratories in terms of labour force (full-time researchers, university professors, PhD and post-doc students, non-researcher personnel) and its features (size of the team, discipline, etc.). We use both publications and patents to characterize the outcome of research activity.

A first originality of our contribution is to analyse via correlations the structure of laboratories in terms of personnel and outcomes. For instance, we question whether and how permanent and non-permanent researchers are connected, how non-researchers are allocated to different labs and the link between disciplines and size. We use simultaneously patents and publications as outcomes of research (while the literature often focuses on one or the other). We enrich this analysis by studying the link between patents and the nature of publications (co-authored with foreign institutions or with firms). We also examine how different types of personnel are linked to various outputs. A second contribution of this paper is related to the construction of a typology of five coherent classes of labs that underline different types of research organization and scientific production. We show that the combination of personnel in the lab is correlated to its performance. In a third stage, we propose an econometric estimation that analyses the determinants of the publication performances of labs in order to test and complement our first results.

If an empirical study such as ours is still lacking (to the best of our knowledge), it is probably due to the unavailability of appropriate data. The constitution of an original and unique database allows us to begin to tackle such issues. The data concern the research activity of more than 80 labs belonging to Louis Pasteur University (ULP) of Strasbourg. ULP is a large and well-ranked European research university, counting nearly 2000 permanent researchers and nearly 100 laboratories belonging to various scientific disciplines.

The remaining part of the paper is organized as follows. The next section presents a literature survey on academic research production and gives the reader some examples of the expected added value of the laboratory level of analysis. The third section provides information on the data and some descriptive statistics. In the fourth section, we develop a correlation study (input–input, input–output, output–output) that stresses some first features of research organization and scientific production at the lab level. The fifth section is dedicated to the typology which synthesises correlations in highlighting the several designs of lab research organization and production. The sixth section presents a study on the determinants of collective publication performance. The last section discusses the main results obtained and concludes.

2. Literature survey

The objective of this part is not to present a detailed review of the broad literature developed by sociologists and economists of science. We have selected among the various topics specific questions related to our paper. With our data we are able to tackle issues relative to the position of the researchers (full-time scientists versus teach-and-research positions), the age of the research personnel, the prestige and the size of the lab and, we also consider patent and publications as two possible outputs. First, we underline results comparable with our findings, even if the levels of analysis or the methodologies differ. Lastly we present some examples illustrating how the laboratory level of analysis may contribute to the present state of our knowledge on academic research production.

2.1. Teaching versus research positions and research productivity

The sociology of science questions whether research and teaching in academia are complementary or competitive activities. Some authors consider them as joint activities in the sense that one reinforces the other. Others regard them as "conflicting roles with different expectations and obligations" (Fox, 1992, p. 293). She used a survey based on a sample of social science faculty to analyse how research and teaching activities influence the publication productivity of social scientists. The study covered four social sciences (economics, political science, psychology and sociology) in BA-, MA-, and PhD-degree granting departments in the US. She showed that faculty members with high publication productivity exhibit strong interest in commitment of time to and orientation to research. They are not strongly involved in both activities, but favour research activities. Her results suggest that the more productive researchers spend fewer hours teaching, preparing for courses and consider teaching as less important than research. Her findings tend to prove that research and teaching are conflicting actions.

2.2. The research context and publication productivity

Empirical studies in the USA found that researchers at prestigious university departments are more productive and cited than their colleagues in lower-ranked universities (Cole and Cole, 1973). A debate about the causality between productivity and department prestige appears. Two hypotheses emerge (Allison and Long, 1990). Is there an effect of the department on the scientist's productivity (departmental effect) or does productivity influence the prestige of the position obtained (selection effect)? These hypotheses are not incompatible and could be mutually reinforcing, but a need to assess their relative importance exists.

Long and McGinnis (1981) based their study on a population of biochemists and defined different organizational contexts[3]: academic versus non-academic sectors and contexts, which do or do not encourage publication. The probability of being employed in a specific context is not strongly influenced by the publication productivity or the citations. Once employed in a specific environment, individual productivity soon conforms to the characteristics of that context. Allison and Long (1990) analysed job changes by scientists within the academic system in four disciplines (physics, chemistry, mathematics and biology). Scientists moving to more prestigious places increased their rates of publication and of citation; those moving to less prestigious institutions showed substantial decreases in productivity. All these results tend to

[3] Long (1978) showed similar results in biochemistry within the academic system only.

underline a preponderance of the departmental effect over the selection one.

Mairesse and Turner (2002) analysed the impact of laboratories characteristics[4] on the individual productivity of CNRS physicists. If the stock of publications of the lab increased by 10%, the individual researcher of this lab would publish in journals receiving 0.26 more citations on average and he would also publish 0.6 papers more per year on average. Thus, the performance of colleagues influences positively individual productivity.

2.3. Age and research productivity

Some economists focused on the publishing activity of scientists in life-cycle models, trying to explain the link between age and scientific production. Diamond (1986) showed that the publishing activity of mathematicians at Berkeley declines continuously with age. Weiss and Lillard (1982) found, for Israeli scientists, that the average annual number of publications first tends to increase, and then to decrease. Levin and Stephan (1991) considered six disciplines and except for particle physicists, publishing activity first increases, reaches a peak around mid-career and declines. Mairesse and Turner, 2002 underlined similar life-cycle effects for a sample of French CNRS physicists. However, Stephan (1996) emphasizes that the explanatory power of these models is rather low and suggests that if an age–publication relationship exists, other important factors probably influence publication behaviours.

Bonaccorsi and Daraio (2002) analysed the research activity of the Italian National Research Council (CNR). They obtained a negative relationship between productivity indicators and the average age of researchers. However, the average age of senior scientists and research directors is not significantly related to productivity. They refuted the hypothesis of a life-cycle effect and assumed that the average age of a laboratory reflects its attractiveness and scientific vitality. They implicitly had in mind the existence of a virtuous circle: higher prestige induces greater resource availability for young researcher positions and thus increases the attractiveness.

2.4. Size and research productivity

At an aggregate level (university or groups of universities), some authors analysed the nature of the returns of scale for scientific production. One of the main problems of measuring the returns of scientific production lies in the possibility to assess all inputs used. In other words, the omission of one or more inputs could unduly lead to revealing decreasing returns. For instance, Adams and Griliches (1996) used data on 50 universities and five scientific fields. They found diminishing returns to the individual university R&D, for the number of papers and the total citations. They changed the nature of the input and replaced R&D by scientists and engineers. The coefficients on papers and citations increased, thus indicating measurement problems linked to the choice of input. In a later work (2000), they considered the scientific productivity of US universities in eight scientific fields. They showed that at an aggregate level, the research production follows constant returns to scale as at the individual university level, diminishing returns prevail. These differences are explained by more important measurement errors at the individual level and by the existence of spillovers, which may only be captured by an aggregate analysis.

At the laboratory level, it becomes less relevant to study returns of scale, nevertheless the size of the lab may be a crucial variable to take into account. Bonaccorsi and Daraio (2002) found that the size of laboratory is never positively correlated with productivity; on the contrary in three domains (chemistry, environment and engineering) size and productivity are negatively linked. In almost all fields the most productive labs are the smallest, and the least productive ones may be large or small. Mairesse and Turner (2002) stressed that the influence of the size of the laboratory on the individual production (in number and quality) is significant but small. The relation is negative for the average number of papers and slightly positive for the citations.

Concerning the production of patents, Wallmark (1998) and Henderson et al. (1998) showed that the largest research organizations apply for more patents. Payne and Siow (2003) and Foltz et al. (2000) found a

[4] They take into account the size of the laboratory (number of researchers), the productivity of the lab, the quality of the publications of the lab (impact factors of the journals) and the degree of international openness (share of papers written with foreign co-authors).

positive and significant effect of federal research funding on patents. Coupé (2003) used patent counts and patent citations as outputs, different R&D lags, types of universities, technology classes, and time effects and concluded to the presence of constant or diminishing returns to scale.

2.5. Patent and publication

Stephan et al. (2002) used data from the 1995 Survey of Doctorate Recipients and analysed the patent activity of a sample of doctoral scientists and engineers, focusing on the relationship between patenting and publishing at the individual level both in academia and in industry. Their main question was whether publications and patents were related activities or not. They first underlined that for the whole sample, less than 20% of scientists applied for at least one patent while 70% published at least one paper in the period covered by the analysis. For academia, these percentages are 10% for patenting and 83.3% for publications. The probability for one scientist to apply for at least one patent is significantly related to whether or not this scientist has published at least one paper. The number of patent applications is positively and significantly linked to the number of papers published. Patenting and publishing activities seem thus to be strongly related at the individual level.

2.6. Expected effects at the laboratory level of analysis

Since we focus on the laboratory level of analysis, our expectation is to shed new lights on the issues mentioned above. Let us briefly present some examples, which may illustrate some of the expected added values the lab level analysis may have in this respect.

The question whether teaching and research are complements becomes really crucial at the laboratory level. In France, a scientist may either be full-time researcher or may have to spend a part of their time to teach. To analyse the complementarity of both positions at the lab level, we will have to test if a "right" proportion of both positions has a positive impact on productivity. Full-time researchers may enhance the connectivity of university professors to frontline research. On the other hand, university professors may improve the productivity of full-time researchers just by driving PhD students to them. This raises new questions in terms of access to non-permanent research human resource (PhDs and post-docs) and its impact on productivity, which are ignored by the specialized literature.

Researcher's age is also an interesting example of a variable that may induce collective effects. In a laboratory, seniors or experienced researchers may increase the productivity of juniors thanks to collective work or simply due to informal contacts. Conversely, junior researchers may stimulate the productivity of older ones, known to have fewer incentives in their late careers. Thus the question does not any more concern the productivity trajectory over the life cycle but concerns gathering researchers of different ages who may be in some respects complementary.

Another issue concerns the relation between the outputs of the research production process. Do patents and publications correlate or exclude each other at the laboratory level? Here again the laboratory level has an added value. The question is no more related to the allocation of the time of one scholar between research projects leading to patents and more fundamental ones. It becomes a question of allocation of resources within the labs: scholars may be specialized on different but complementary research agendas, which may or may not have a potential for patenting; scholars may also benefit from the presence of non-permanent researchers especially allocated to patenting activities. It may also be an issue of managing research agendas having different time lines.[5]

3. The data

The objective of this part is to present the general context of our statistical analysis. We will briefly describe the different research activities of Louis Pasteur University and its scientific reputation. Then, we will explain the way we collected the data, present their characteristics and richness and provide some results of the distribution of labs.

[5] For some empirical evidence on the management of research agendas in laboratories and how this influences their strategies for collaboration with firms one may see Carayol (2003b) and references therein.

3.1. Louis Pasteur University

The data concern the research activity of one single university, namely Louis Pasteur University (ULP) of Strasbourg. This university is quite large and diversified. Seventeen separate institutional components (i.e. engineering schools, teaching and research units, and various institutes) are located in six campuses in the Strasbourg area in which around 18,000 students are enrolled. Research and teaching activities cover a wide range of subjects in the fields of medical sciences as well as mathematics, computer science, physics, chemistry, life sciences, geology, geophysics, astronomy, engineering sciences. Human and social sciences are also present in the specific fields of economics, management, geography, psychology and educational sciences.

ULP has an old tradition of fundamental research and a long-term standing of scientific excellence. Its researchers have received numerous national and international scientific prizes, including the Nobel Prize for Chemistry awarded to Jean-Marie Lehn in 1987 for his contribution to the field of Supra-molecular chemistry.[6] Overall, ULP is one of the largest French universities in terms of research. The Third European Report on Science and Technology Indicators 2003 ranks it first among the French universities in terms of Impact and 11th among European universities. Such research capacity is enhanced by a close-knit with the major national research bodies such as the National Centre for Scientific Research (CNRS) and the National Institute for Health and Medical Research (INSERM) present in the Strasbourg area.

3.2. The variables and some descriptive statistics

The presentation of the variables depends mainly on the method used to collect them. We collected data related to the personnel and the laboratories from internal administrative sources. Information related to publications came from the ISI Web of Science, and the French Patent Office provided patent data. We will present the characteristics of our variables and the way labs are distributed according to these variables.

3.2.1. Laboratories and personnel

We collected the variables from administrative reports completed for the 1996 contractual affiliation round. Such a round occurs every four years. All laboratories (and also faculties and institutes) have to produce a standardized document, which is usually divided into two distinct parts: (i) a précis of the past four years and, (ii) a project for the next four years. Thus the data concern the period from 1993 to 2000, which may be separated into two four-year sub-periods: 1993–1996 and 1997–2000. These documents are evaluated through standard peer review procedures conducted by both the Ministry of Research and Education and funding agencies such as the CNRS and INSERM whose support is expected. We recorded their decisions concerning the affiliation. The affiliation to CNRS and INSERM means increased funding for research facilities and positions. The affiliation operates through a peer review process mostly taking into account scientific production arguments and constitutes clearly a signal of the labs scientific excellence.

We collected the standard information mentioned in those documents. We gathered many typical information about the personnel of the labs, specifying the number of individuals in each detailed category of personnel and individual information on permanent researchers including the name, the sex, the age and the status.

Concerning the status, in France permanent researchers may occupy two types of positions: either a university professor type position (with teaching and research) or a full-time research position. The former belong to the university while the latter are employed directly by the large national public research organizations such as the CNRS or INSERM. Nevertheless both categories work together in the university labs.[7] In addition, for both categories, there is a clear promotion (from Assistant Professor to Full Professor; or from Researchers to Director

[6] Also Ferdinand Braun was awarded the Nobel prize in 1909 in physics for his radio telephone (together with Marconi). Other Nobel price or Field Medal winners spent some time in their careers at Strasbourg University: Wilhem Roentgen, Alphonse Laveran, Hermann Staudinger, André Lwoff, Louis Néel, Louis Pasteur, René Thom.

[7] These institutions also have some labs independent of the universities, but these are not to be found in our sample, and so we do not consider them.

of Research) at mid-career on the basis of scientific productivity. Such a promotion does not imply tenure since, in France, Assistant Professors and Researchers are tenured from the very beginning of their careers. Nevertheless it implies a significant increase in wages and social status within the academic sphere.

We recorded 83 distinct laboratories in 1996. We have reliable and complete information for all but two of them about for which we miss the complete characterization of their permanent researchers. Thus for such variables as grade, age, sex of permanent researchers, a sub-population of 81 labs will be considered. Among the 83 labs, 43 are funded by the CNRS,[8] nine by INSERM, while 31 are supported by the Ministry of Research and by the resources of ULP. Among the 1460 permanent researchers, 760 are full-time researchers directly paid by the CNRS and INSERM and 700 are university scholars. On average, the permanent researchers are 51.5 years old. Among them, 360 are females (24.6%). Fifty-seven percent of permanent researchers occupy junior-like positions. We also find some 1940 non-permanent researchers: 1230 PhD students and 710 post-docs. Lastly some 1120 non-researchers (administrative staff and technicians) and 410 visitors are recorded.

ULP laboratories are rather small in terms of permanent researchers: 61 labs, i.e. 74%, have less than 20 permanent researchers and eight declare more than 41 scientists. The distribution for non-permanent researchers exhibits the same characteristics: 70% of labs have less than 20 non-permanent researchers and 21% more than 41. For a large majority of labs (53, i.e. 65%), more than 50% of permanent researchers occupy junior-like positions. The average age of permanent scientists is above 50 in 70% of the labs, five labs have an average age between 40 and 45. Women represent less than 25% of the permanent researchers in 53 laboratories (65%).

We also got the main scientific disciplines of the labs according to the specific categories defined by the University. These are the following: astronomy (1 lab), biotechnology (12 labs), chemistry (9 labs), genetics and cellular and molecular biology (9 labs), geography (2 labs), mathematics (1 lab), mechanics (1 lab), medicine (22 labs), odontology (1 lab), neurosciences (7 labs), condensed matter physics and chemistry (4 labs), subatomic physics (2 labs), earth sciences (2 labs), information sciences and technology (3 labs), humanities and social sciences (8 labs).

To complement such information, we used data we had on permanent researchers in order to collect information on their disciplinary affiliation at the most detailed level possible as indicated by the institutions to which they are affiliated (University National Council, CNRS, INSERM). Such classifications do not perfectly match at the sub-discipline level we are interested in. Nevertheless, thanks to a normalization grid produced by the OST (Observatoire des Sciences et Techniques) specifically for the French system, we were able to allocate nearly all permanent researchers to 50 different sub-disciplines according to a unique nomenclature selected as the reference (namely the one of the National University Council) (sub-discipline level normalized through the OST nomenclature; cf. OST, 2003). We found that 11 laboratories are mono-disciplinary, 15 have two disciplines, and 21 have three disciplines. The mode of the distribution is four disciplines in 22 labs. The maximum number of disciplines is eight and only two laboratories are concerned.

3.2.2. The outcomes

Our database also integrated information about the various outcomes of research production, namely publications and patents. For each permanent researcher we collected his/her published articles (using SCI, SSCI and Arts and Humanities ISI databases). We found more than 26,000 occurrences over the 1993–2000 period. This amount includes some double counting as quite a few ULP researchers may have co-authored papers. By dividing each occurrence by the number of co-authors we obtain the effective (normalized) scientific contribution of each author.[9] The total scientific performance is 6040. The median number of co-authors is five. We differentiate between two types of co-authorship. A co-publication is "international" if at least one co-author belongs to

[8] Two types of association with the CNRS exist: UMR (Unité Mixte de Recherche) and UPR (Unité Propre de Recherche). The latter is more closely supported by the CNRS. Nevertheless, these labs may be supported by the university and/or may host university researchers.

[9] Since publication data were collected from our list of permanents, an author is necessarily a permanent researcher.

a non-French institution. Some 10,400 occurrences (i.e. 40%) exhibit international co-authorship. We also screened co-publications in which at least one of the co-authors belongs to a firm. One thousand and two hundred publication occurrences with industrial partners exist and represent 4.6% of all publication occurrences.

Concerning the total scientific performance, 67 laboratories have published between 1 and 100, the distribution between these labs is heterogeneous and the mode is 20–40 publications in 18 laboratories. Three labs have published between 300 and 500 papers. The distribution of the average performance by permanent researchers is uni-modal. The mode of the distribution is an average of 2–4 articles per permanent researchers in 27 laboratories. Twelve laboratories show an average of more than eight papers. These results show that a small number of labs publishes a large amount of papers and that a large number of labs publish a small number of articles in a quite similar fashion as at the individual level as first evidenced by Lotka (1926).

The behaviour in terms of co-publication is rather contrasted: in five laboratories the average number of co-authors is between 1 and 2 and in five other laboratories the average is above 8. The mode is 5–6 co-authors on average for 30 laboratories. The distribution of international co-authorship is heterogeneous. In nine laboratories, more than 50% of the publications are international. In 62 laboratories, less than 37.5% of the papers signal a foreign co-author. The mode is between 25 and 37.5% of international publications in 28 laboratories. Ten laboratories never published with industry and at the other extreme one laboratory published between 25 and 30% of its papers with industrial partners. The mode is between 0.1 and 5% of publications with private partners in 38 laboratories.

We also looked for the French and European patents, which had been invented by at least one of the ULP permanent researchers. To do so we matched our permanent researchers table with the patent data provided by the French Patent Office (INPI) covering the same 1993–2000 period. We found 850 occurrences of French or European patent applications. After a cleaning process, which eliminated the extensions of French to European patents, we ended up with 463 patents invented by researchers from ULP over the 8 years considered. Some 189 patent applications were recorded in the first sub-period (1993–1996) and 274 in the second one (1997–2000) giving an increase rate of 45% between the two sub-periods.

The distribution of patent applications over the labs is skew. Thirty-eight laboratories have no patent, 31 laboratories have between 1 and 10 patents, five laboratories have between 11 and 20 patents and one lab obtained between 51 and 60 patents. The distribution of labs according to the number of patents per permanent researcher also shows a decreasing shape. In 26 laboratories, the number of patents per permanent researcher is between 0.01 and 0.5, and in eight laboratories it is between 0.5 and 1. Finally, two labs have between 2 and 4 patents per permanent researcher.

4. A first analysis of the structure of the labs

The objective of this section is to provide a first analysis of the structure of the laboratories in order to infer some intuitions to build our typology. To reach this aim we conduct correlation studies.[10] The first set of correlations describes the common and potential distinctive features of the organization of laboratories in terms of types, number and disciplines of personnel. The second group of correlations provides information about how publications and patents are linked to each type of personnel. Finally, we also study output–output correlations in order to have a first investigation about whether the labs, which publish more, are also the ones that patent more and if the nature of the publications counts. Distinguishing between sub-periods may help us track causal relations.

4.1. The organization of labs in terms of personnel

We mainly use the various characteristics of the personnel to analyse the organization of research laboratories. We provide results about the way permanent and non-permanent researchers are linked, about the allocation of non-researchers and about the link between size and disciplines.

[10] All correlation coefficients reported in the text have a significance level exceeding 95%. A coefficient higher (lower) or equal to 0.3 (−0.3) reaches the 99% significance level.

4.1.1. The specific attraction power of full-time scientists and university professors

University professors are usually associated with full-time researchers (0.35) within labs. Full-time researchers are personnel belonging to the public research organizations such as CNRS or INSERM. This result is not surprising as university labs affiliated to these organizations usually involve both types of personnel, but in various proportions.

We also find that the number of permanent researchers and the total non-permanent researchers are significantly correlated (0.66). At a more disaggregated level, we notice that PhD students are primarily correlated with professors (0.67). Nevertheless, they are also strongly correlated with CNRS researchers (0.60). This result does not mean that full-time researchers often supervise PhDs. It could be due to the fact that CNRS researchers are mainly located in the most recognized labs, which may provide more grants, thus attracting more PhDs. That observation seems to be supported by the fact that PhDs are negatively correlated with EA (Associated Teams) laboratories (−0.32). The latter are only supported by the Ministry of Research and involve only a few full-time permanent researchers. Thus, PhD students seem to be primarily allocated to laboratories in which university professors are present. This may be explained by the importance of personal contacts during the late stage of their graduate studies. Excellence also matters for the matching process of students to labs, but appears to be secondary.

On the contrary, post-docs seem to value only fame and excellence when choosing labs, especially foreign post-docs who are correlated with CNRS researchers (0.46) and high institutional recognition (0.23), especially in UPR-type of CNRS association (0.32). They are not correlated with university professors while at least a small but significant correlation was expected.

4.1.2. The non-research personnel are allocated according to disciplinary practical needs

The non-researcher personnel are strongly correlated with CNRS scientists (0.70) and with non-permanent researchers (0.72). Their allocation seems to be also very dependent on the disciplinary environment. Non-researchers are correlated with subatomic physics (0.47) and genetics and cellular and molecular biology (0.23), which require (especially the former) heavy instrumentation and many technicians and engineers. One may observe that the presence of non-researchers is not significantly correlated with any variable characterizing the institutional recognition of the labs. These observations tend to support the hypothesis that non-researchers are mainly allocated for practical needs (determined by disciplinary environments) and through a pure linear scale fashion not being driven by excellence or reputation considerations.

4.1.3. Labs of different disciplines have different sizes

When looking at the disciplinary differences, we found that the laboratories in medicine tend to be of a smaller size. These labs seem also to have a rather low institutional recognition. This may reflect a low quality of research but also explain their ability to get substitute funding from their simultaneous commitment within the University Hospital. In that respect, the laboratories specialized in the promising and rapidly growing field of neurosciences are exactly the opposite: funding agencies support them.

The labs in genetics and cellular and molecular biology, which are also of a big size especially considering the number of post-docs, appear to be strongly supported by funding agencies. Subatomic physics labs are also of a large size, but only in terms of CNRS permanent scientists and non-researchers (technicians), but not in terms of non-permanent researchers (PhDs or post-docs).

4.2. Different positions lead to various scientific performances

The aim of this part is to study the connections between the various outcomes of research and the characteristics of the personnel. We examine respectively the contribution of university professors, full-time scientists and non-permanent researchers. By contribution, we mean publications in general, but also those co-authored with researchers belonging to foreign institutions or to private firms and patents.

4.2.1. The unequal contributions of university professors

One main and probably not-so-surprising observation concerns the productivity of university professors.

The correlation between publication performance per permanent researcher and university professor is negative (−0.30). Moreover, university professors are negatively correlated with the share of authors among permanent researchers (−0.29) while there is no significant correlation between university professors and both the variance and the kurtosis of performance among authors. Thus apparently, professors who publish may be quite as productive as CNRS researchers while other professors totally gave up publishing. This difference may be explained by the fact that some faculties favour research activities and others dedicate more efforts toward administration or teaching activities. This result could thus be justified by the idea developed by Fox (1992) that teaching and research may be considered as conflicting activities (cf. Section 2.1).

4.2.2. The weak performances of junior positions

Publication performance is also strongly negatively correlated with "junior" positions (−0.42). This result could be explained by a lack of experience of younger researchers. Nevertheless, scientific performance appears not to be significantly correlated with age. Several complementary explanations may be provided. Some junior scientists may probably be un-promoted researchers with lower research abilities or publication incentives. Or, this result may be partially influenced by the fact that a high share of junior researchers occupies Assistant Professor positions, combining teaching, research and administrative activities.

The share of publications written with at least one industrial partner is negatively correlated with both university professors (−0.30) and junior-like scientists (−0.26). They both seem to be more oriented toward the scientific community. As both categories are also the least productive ones, they may not be attractive in the eyes of potential industrial partners. This observation is congruent with the fact that the kurtosis of the distribution of industrial collaborations among authors is correlated with university professors (0.78). The latter is also true concerning PhD candidates (0.57), who may "fuel" such collaborations.

4.2.3. Full-time scientists publish and patent

Full-time researchers are strongly correlated with the number of publication occurrences and with the publication performance. CNRS researchers have strong connections with the international scientific community: their correlation with the share of international collaborations among all publication occurrences is 0.34. A scale issue seems to appear since this share is correlated with the number of permanent researchers (0.31) and the number of non-researchers (0.31). Nevertheless, the latter result may be due to an indirect effect since there are more non-researchers in labs belonging to disciplines such as subatomic physics in which publications count impressive numbers of co-authors. The variance of international collaborations among authors is strongly correlated with both CNRS researchers and non-researchers. The kurtosis of the distribution of international collaborations among authors is equally correlated with all size variables: this seems to indicate that when size increases, the long-range collaborations are more concentrated on a lower share of permanent researchers.

CNRS researchers are the most important contributors (0.55) to patent production, while university professors are not significantly correlated with patent production. This may be due to historically grounded differences, which may be progressively reduced: university professors are positively correlated with an increase in patenting (0.24) and with a move from non-patenting to patenting (0.25) between the two sub-periods. A possible scale effect may exist, since we observe that CNRS researchers and PhDs are also correlated with the increase rate in patenting activity (0.49 and 0.40). Nevertheless this explanation may be controversial and the results may primarily express a progressive popularity of the patenting activity among the scientific community.

4.2.4. Non-permanent researchers are important actors in the patenting process

Finally, the distribution of publication performance among authors within labs may be affected by the presence of non-permanent researchers: the variance of publication performance is correlated with foreign post-docs (0.33). Moreover PhDs and foreign post-docs are strongly correlated with the kurtosis of scientific performance distributions among authors (0.37 and 0.47). These results seem to indicate that the hosting of non-permanent researchers benefits unequally to the permanent researchers of the lab. Their efforts are probably allocated to the benefit of the most famous scientists or, in other words, post-docs are strongly attracted by labs with a few highly productive researchers. These explanations could in some ways be supported by observing that there is a high correlation between the kurtosis of the number of co-authors and the PhDs and foreign post-docs (0.41 and 0.44), indicating that the more numerous the non-permanent researchers the skewer the distribution of co-authors among publications.

The non-permanent researchers seem to be even more important for patenting than the permanent researchers (high correlation coefficient especially for post-docs 0.69). The French post-docs are correlated with the patenting productivity of permanent researchers (0.24). Permanent scientists may probably assign more applied (even if potentially less academically rewarding) problems to French post-docs. The latter may also be willing to select these more applied activities in order to acquire a first practical experience valuable on the private job market. Finally non-researchers are also correlated with patents (0.51).

4.3. Correlations between outcomes

We first look at the potential correlations between the publication performance and international co-publication on the one side, and industrial co-publication, on the other side. Next we turn toward the potential reinforcement or exclusion between publishing and patenting.

4.3.1. Industrial and international publications are correlated

The share of international co-publications among all publications is not correlated with the publication performance per permanent researcher apparently indicating that the labs which collaborate more with international partners are not the ones that publish more on a national basis. Nevertheless the share of international publications in the first sub-period is correlated with the publication performance (0.26) indicating probable scale or threshold effects in publication performance of the laboratory for getting access to international publication networks.

Industrial collaborations per permanent researcher are strongly correlated with publication performance per permanent researcher (0.52) indicating that the labs, which publish more, have also more research collaborations with firms. Moreover, it appears that the labs in which permanent researchers are the most connected to the international scientific community are also the ones that collaborate more with firms. That may express the fact that internationally visible scientific labs tend to attract more firms.

4.3.2. Publications and patents are related activities

The hypothesis that pure scientific productivity is related to invention appears to be strongly supported by the data against the exclusion hypothesis: the publication performance per permanent researcher is strongly correlated with the patents per permanent researcher (0.33). The result is also true when looking at the correlation with patents per researcher, even if less strongly (0.24). Since the increase in patenting is strongly correlated with the whole publication performance (0.37) there may be a scale effect here. Our results seem thus to confirm the findings of Stephan et al. (2002) (cf. Section 2.5).

Patents per permanent researcher and patents per researcher are even more strongly correlated with collaborations with industry (0.44 and 0.37). The causality seems to go this way since the rate of increase in patenting between the two sub-periods is strongly correlated with the collaborations with industry (0.49). The intensity of publication collaborations with industry seems to be important for the intensity in patenting since the share of industrial collaborations among all publication occurrences of the lab are positively correlated with patents per researcher and permanent researcher (0.27 and 0.29).

Patents are also related to international co-publication: the rates of increase in patenting and international publication occurrences are correlated (0.29). Nevertheless the size issue may generate such results. The important observation is that the number of international collaboration occurrences is the only variable significantly correlated with the “zero to positive” patenting dummy (0.29). Such a result tends to indicate, in the second sub-period considered, that the most internationally connected labs may have shifted from a non-patenting and exclusive publishing behaviour to a patenting behaviour.

To support that observation and more generally, the recent patents seem to be more strongly correlated with publication performance than the ones of the first sub-period: patents in period 1993–1996 are correlated with publication performance of the two

Table 1
The qualitative variables used for building the typology

Variable	Description	Modalities
Univ-prof	Number of university professors	High, medium, low
Full-time-res	Number of full-time researchers	High, medium, low
PhD	Number of PhD students	High, medium, low
Post-doc-f	Number of foreign post-docs	High, medium, low
Post-doc-n	Number of national post-docs	High, medium, low
Junior-pos	Share of junior positions (non-promoted) among permanent researchers	High, medium, low
Age-perm	Average age of permanent researchers	High, medium, low
Non-res	Number of non-researchers	High, medium, low
Disc-entropy	Sub-disciplinary entropy within the lab	High, medium, low
Authors-perm	Share of authors among permanents	High, medium, low
Perf-perm	Average publication performance normalized of permanent researchers	High, medium, low
Var-perf	Variance in publication performance (norm) among permanent researchers	High, medium, low
Patent-perm	Patent invention performance per permanent researchers	High, medium, low
Instit-recogn	Institutional support by national agencies as CNRS or INSERM	High, low
Pub-internat	Share of international collaboration among publication occurrences	High, low
Pub-indus	Share of international collaboration among publication occurrence	High, low

sub-periods with coefficient 0.55 and 0.54; while patents of sub-period 1997–2000 have the following correlation coefficients with the publication performances: 0.65 and 0.64. This may indicate that patents tend to be increasingly grounded in publication performance without any feedback decrease publication.

5. The typology of laboratories

As we have seen earlier, the labs differ according to both their input and their output structures. Moreover we have obtained many insights on how the variables correlate. We are now turning toward a deeper analysis that should allow us to identify various "styles of research production" at the lab level. There are obviously different solutions to associate inputs in labs that generate different amounts of the two types of outcomes. Since our typology is intended to mix both considerations, the variables retained for the MCA are related to both. The variables used for building the typology are presented in Table 1. All variables have been transformed into qualitative variables having two or three modalities. Information on the variables selected are presented in Table 1. The typology is built for the 81 labs about which we have complete information on the above-mentioned variables of interest.

To build the typology of laboratories we follow a standard methodology composed of a multi-correspondence analysis (MCA) followed by an ascendant hierarchical classification (AHC).[11] Following the MCA, we selected four axes, which collectively represented 39.13% of the inertia. Then, the AHC was realized based on the co-ordinates of the labs on these four axes. Five coherent classes of labs were selected because, in retaining these five types, the within-classes variance of the total variance was nearly 44.7%, which is usually admitted to be a good ratio. Then the centres of the classes obtained may be represented on the four axes space (cf. Figs. 1 and 2).

As Fig. 1 shows, the first axis (contributing for 14.1% of the inertia) accounts for the size of labs and other variables, which are structurally associated with scale issues such as institutional recognition and share of international collaborations among publications which have been highlighted to be subject to scale effects. On this axis, the fifth class is mainly opposed mainly to class 2 and to the other classes to a lesser extent. The second axis (10.3% of the inertia) opposes strongly research-intensive labs with the ones also concerned with teaching and PhD supervision. Along this axis class 4 (and to a lesser extent class 1) is opposed to class 2 (and 5 to a lesser extent). Fig. 2 gives the projections of the variables modalities and the classes on the last two axes. The third one (8% of

[11] The reader might refer to Greenacre (1993) or Benzécri (1992) for a precise description of the methodology.

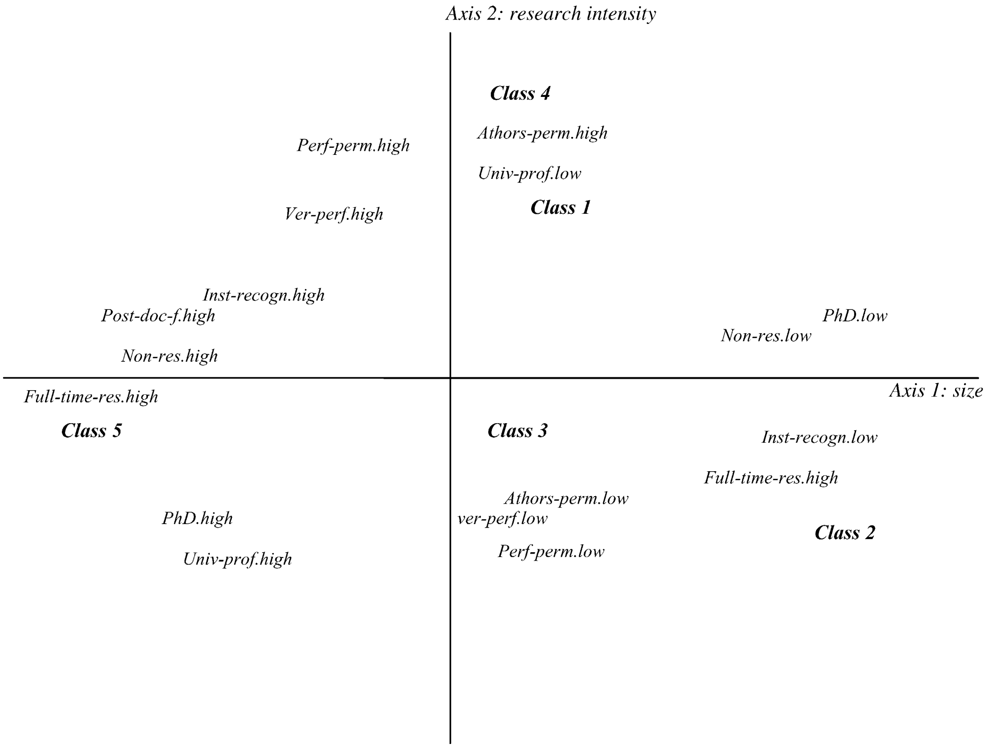

Fig. 1. The centers of the classes and the variables contributing to the fist and second axes of the MCA.

the inertia) opposes highly publishing labs to the ones, which are more median in that respect. According to this axis, classes 4 and 3 are especially distant. The last axis retained (6.5% of the inertia) illustrates the distinction between younger, more international more attractive toward post-docs and more open toward industry to older, less attractive and less connected with firms. This is why we synthetically labeled this axis “openness intensity”.

5.1. The classes of laboratories

In this part, we discuss the characteristics of the five classes. Some of our arguments are based on descriptive statistics, which are not presented due to space constraints but can be produced upon request. In a second subsection, we discuss and test what we can lean from comparing classes.

5.1.1. Class 1: the standard research intensive labs

Class 1 involves 22 labs. The laboratories of this class are of a rather small size and “research intensive” since they count on average a high share of full-time researchers as compared to university professors. They host only few PhDs and few post-docs, which is quite surprising considering their research-intensive nature. The ratio of permanent researchers over all researchers is high (50% on average). The simultaneous presence of many non-researchers reflects a probable substitution between non-permanent researchers and non-researchers. While the labs have on average fewer sub-disciplines than other labs (probably due to their small size), their entropy index is the highest. The average age of permanent researchers is higher than average. Moreover, the share of junior-positions lies below average, which may indicate on average lower abilities of these permanent researchers.

The scientific performance of these labs is higher than that of the average labs, with 5.96 papers written (in individual contribution) per permanent researcher. The papers are written on a less international basis even if permanent researchers have written as many internationally co-authored papers as the average. The collaboration with industry is below the average.

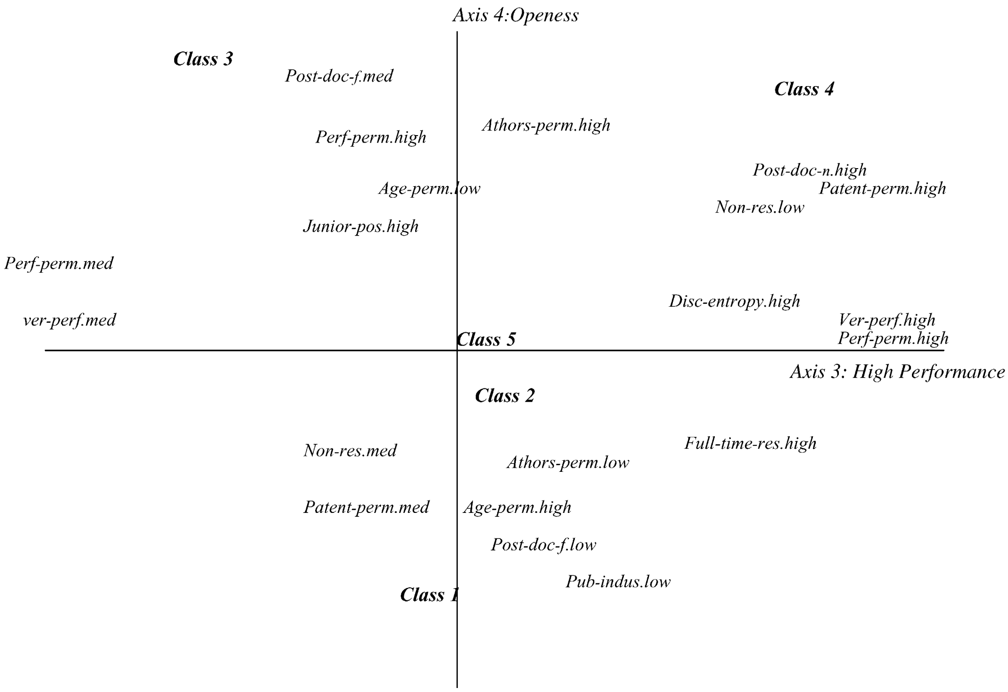

Fig. 2. The centers of the classes and the variables contributing to the third and fourth axes of the MCA.

This may help explain that permanent researchers produce only 0.12 patent, (one-third of the average). Sixty-three percent of the labs never patented over the period. The labs belong mainly to the medicine field, most of the labs are involved in neurosciences, one in chemistry and one in bio-pharmacy. The labs of this class are nearly equally shared between high and low recognition which implies that this class counts a third of the less recognized labs and half of the labs supported by INSERM. This observation led us to compare the characteristics of the highly recognized ones with the other ones. The two noticeable differences were that the recognized ones count more full-time researchers, attract more non-permanent researchers and tend to publish substantially more. Nevertheless the two sub-groups are quite similar in all other respects, especially concerning the rather low inventing activity.

5.1.2. Class 2: the teaching oriented labs in the fields of social and human sciences

This class gathers 10 labs, among which we find eight belonging to the social sciences, humanities and geography (the remaining two belong to bio-pharmacy and biology). Their size is below average. Permanent researchers are mainly university professors (the share of full-time researchers is close to zero). They count many PhD students and nearly no post-docs. The share of females among permanent researchers is higher than the average (28% against 23%).

Eight of the labs are not supported by the funding agencies. The share of authors among permanent researchers is extremely low: only 45% of permanent researchers publish. Considering these authors, their average performance is only one-third of the average performance of authors in labs. Only few of the publications are written through international cooperation and the collaborations with co-authors outside academe represent only 1.6% of the publication occurrences.

5.1.3. Class 3: the non-research intensive and industry oriented labs

Class 3 counts 15 labs with a size below average. They are “non-research intensive” as we find mainly professors and only few full-time researchers.

This explains the presence of many PhDs and few post-docs. Moreover, the share of permanent researchers is higher than average (54% against 47%). Permanent researchers are much younger than the average, and the junior-like positions represent 70% of the permanent positions.

The ratio of authors among permanent researchers and the publication performance of authors are below average. They publish 1.63 papers less than in the average labs. Nevertheless, the proportion of international collaborations is higher than average as well as the share of collaborations with industry (8.7% of the publications of the labs). But this did not favour very much patenting activity since their average inventive performance is still below the general average (only 0.3 patent per permanent researcher). These specificities are probably not related to their disciplinary peculiarities. The labs belong to various disciplines: five labs are active in bio-pharmacy, two each in biology, physics-related fields, engineering and medicine, and one each in chemistry and neurobiology. Nearly half of the labs are supported by the CNRS.

5.1.4. *Class 4: the elite research intensive labs*

The 12 labs of class 4 are of a small size even if slightly bigger than the ones of class 1 and smaller than the ones of class 3. The share of full-time researchers among permanent researchers is slightly below average. The share of juniors and the average age are both below the average of all labs. This tends to indicate a quite good individual recognition of the permanent researchers. The ratio of permanent researchers is the lowest of all classes (only 38%). This comes from numerous PhD students (nearly as many as in class 3 but with much fewer professors), twice as many national post-docs and more than three times as many foreign post-docs than in class 1. With the same number of sub-disciplines as average, the sub-disciplinary entropy is the highest (0.9) but never very high (maximum at 1.3).

These labs exhibit a strong cohesion. Only 2% of the permanent researchers do not publish at all. Permanent researchers publish on average 2.8 papers more than the average, and authors publish 1.6 papers more than the authors of class 1 (the other research intensive class). While the share of international collaborations among publication occurrences is below average, the number of international collaborations is clearly the highest compared to all other classes. With 8.7% of the publication occurrences being co-authored with industrial partners, the number of industrial collaborations per permanent researchers is more than twice the average. This probably contributes to explaining that most labs of this class patent (85%) and that they patent nearly twice as much as the average (10 patents invented) and nearly three times as much per permanent researcher (more than one patent per permanent researcher). These labs belong to different disciplines: five belong to medicine, four to bio-pharmacy, two to chemistry, and one to biology.

5.1.5. *Class 5: the large laboratories*

This class covers 22 labs, which may be distinguished by their large size. They have 37 permanent researchers on average. Most of them benefit from an important support from CNRS, which allows them to accommodate more than 20 full-time researchers on average. This is the highest ratio of full-time scientists over permanent researchers among all classes. The ratio of permanent researchers is quite similar to the average, but these labs have fewer PhD students and essentially more foreign post-docs. They also count many non-researchers. Age, share of junior-like positions, share of females, entropy are similar to average.

One should notice that neither the size nor the important ratio of full-time scientists allowed these labs to be more productive: their patenting and publication performances per permanent researcher are similar to the average (even if the patenting activity is increasing, 20% of the labs do not patent at all). The share of international collaborations is higher than average but that may be due to a higher number of co-authors. The share of collaborations with industry among publication occurrences is below average. These labs belong to a very large range of disciplines: five in chemistry, five in biology, four in physics-related fields, two in engineering, two in earth sciences, one each in bio-pharmacy, astronomy, mathematics and neurosciences.

5.2. *Do organizational aspects really explain scientific performances of labs?*

The typology helps understanding the relations existing between a group of input variables and a set of outcomes. One important conclusion of the typology exercise may consist in proving that the way personnel are associated within labs has an impact on the collective productivity. We highlight the existence of a virtuous combination of factors leading to both high publishing and high patenting performances.

Indeed, some labs (class 4) are by far the most productive in terms of publication performance and (even more) in terms of patents. These labs exhibit an interesting combination of inputs: permanent researchers are specialized in different sub-disciplines (highest interdisciplinary entropy), are nearly equally split between professors and full-time researchers (with an slightly higher share of teach-and-research positions) and, attract many non-permanent researchers. If we compare these labs with those of the classes 1 and 3,[12] we shall see that although they have quite comparable sizes, they exhibit different input structures inducing different output performances. Class 3 is more oriented toward teaching and PhD supervision while having few post-docs and a below average publication performance. Class 1 is the more “research oriented” with more full-time researchers than university professors among permanent researchers. These labs publish significantly more than the average. Nevertheless, they publish even less than the labs of class 4 and their patent performance is only one-third of the average.

However, there may be main important potential shortcomings that might alter these conclusions. These are the following.

(i) Classes and disciplinary differences: Even if the information on lab disciplines has not been used as such to build the typology, there are strong expectations that classes and disciplines are not independent. As a matter of fact we have observed that class 2 groups together all labs from social sciences. The question is to what extend are disciplines and classes related. At this stage we still do not know whether belonging to a given class does or does not only translate the specific organization and performances of a given discipline.

(ii) Internal coherence of classes according to outcomes scores: The (average) scores in outcomes of labs that we have used to compare classes (especially class 1 versus class 4) might hide an important heterogeneity with respect to such variables. The within-classes coherence that is ensured by the procedure used to build the typology might be essentially effective on the other variables used (listed in Table 1) so that the labs of a given class cannot be clearly associated to the mean values of outcomes.

(iii) Disciplines and average outcome scores of classes: Even if the risks contained in (i) and (ii) are at least partially avoided, it remains possible that the differences in average outcomes of labs between classes may only be due to the relative representation of some disciplines. If so, there is no valid statement on the relation between research organization and production performance that can be derived from comparing average performances of labs in different classes.

The evidence presented in Tables 2–6 allows us to account for these three potential biases and thus to confirm our statement on the relation between research organization and production performance.

Table 2 shows that as expected, the disciplines are not uniformly present in classes. Eighty percentage of labs in class 2 belong to social and human sciences, labs in class 5 are predominantly in the fields of biology, chemistry and physics, the ones of class 3 are quite evenly distributed among disciplines (excluding social and human sciences and mathematics). Classes 1 and 4 are exclusively concerned with biology, pharmacy, medicine and chemistry. Nevertheless, 68% of the labs in class 1 are in the field of medicine while only 42% of class 4 are in this field. From these observations, we can conclude that if classes and disciplines are far from being independent, one cannot state that classes only reflect disciplinary difference in knowledge production. If we consider specifically classes 1 and 4 that have been most compared: both have labs of the same set of disciplines but with different shares of each discipline.

Tables 3 and 4 show how the labs in classes are allocated with respect to performances in publication and patents per permanent researchers. We observe that performance scores within classes are not homogeneous. Some classes such as classes 5 and 1 exhibit high internal heterogeneity both for publications and patents. Nevertheless, the differences observed

[12] Since classes 2 and 5 tend to be very specific (class 2 brings together social sciences and class 5 assembles big labs) we leave them aside to concentrate our comparisons between classes 1, 3 and 4.

Table 2
The disciplinary association of classes' labs (cross-table disciplines/classes)

	Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)	Class 5 (%)	Total
BIO	23	10	20	8	27	16
PHARMA	5	10	33	33	5	12
MED	68	0	13	42	0	22
CHEM	5	0	7	17	23	9
PHYS	0	0	13	0	32	9
ENG	0	0	13	0	9	4
MATH	0	0	0	0	5	1
SHS	0	80	0	0	0	8
Total	100	100	100	100	100	81

Table 3
The publication (per permanent researcher) performance of labs in classes: cross-table classes/deciles of *perf-perm*

	Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)	Class 5 (%)
1	0	70	13	0	0
2	5	20	20	0	9
3	0	10	20	0	18
4	14	0	13	0	14
5	18	0	13	8	5
6	9	0	13	8	14
7	14	0	7	17	9
8	9	0	0	17	18
9	14	0	0	33	5
10	18	0	0	17	9
Total	100	100	100	100	100

between classes 1, 3 and 4 remain valid: the publication performances of class 3 labs are clearly below, class 4 labs overcome the performance of other classes with regard to the two outcomes scores, patent production counts for the class 1 labs are clearly below the other classes' ones. Thus the statements on the relative productivities of classes 1, 3 and 4 based on average performance scores still hold.

Table 4
The patent (per permanent researcher) performance of labs in classes: cross-table classes/deciles of *patent-perm* (with the five first deciles being joint in one category since a bit more than half labs do not patent)

	Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)	Class 5 (%)
1	64	90	67	17	14
5	0	0	0	0	14
6	23	0	0	0	14
7	5	0	0	8	27
8	0	0	13	25	14
9	9	0	7	17	14
10	0	10	13	33	5
Total	100	100	100	100	100

Tables 5 and 6 allow us to compare between labs scores of different classes, by controlling for disciplinary differences. Let us first focus on the comparison between labs in classes 1 and 4. It is shown that, for all disciplines but chemistry, labs in class 4 are more productive than the ones in class 1. For instance biology labs in class 4 are in average nearly three times more productive in terms of publications than the ones of class 1 (12.89 versus 4.34 papers), while pharmacy ones are twice as productive (6.91 versus 3.49). As regards to patent production, the differences between labs of the two classes are even more remarkable. Let us now consider class 3. The publication performance of these labs controlling for disciplines remains clearly below the ones of classes 1 and 4. On the contrary, results in terms of patent production (Table 6) speak for a careful use of class 4 average patent production performance. Indeed, patenting scores for the labs of this class are specifically due to labs in pharmacy and engineering sciences while labs in other fields have no patents.

6. The determinants of publication performance

This section is dedicated to specifically studying the determinants of laboratories publication performance. For that purpose we have run an OLS linear regression on *perf-perm* which is the publication performance per permanent researcher of the lab. Such study cannot provide the same richness than the typology,

Table 5
The publication per permanent researcher performance of labs in classes and disciplines (mean values of *perf-perm* and standard errors in parentheses)

	Class 1	Class 2	Class 3	Class 4	Class_5
BIO	4.341 (2.525)	0.526 (0.526)	3.583 (1.527)	12.892 (–)	5.012 (1.892)
MED	6.585 (3.532)	– (–)	3.542 (0.181)	7.348 (3.436)	– (–)
PHARMA	3.494 (–)	2.217 (–)	2.925 (1.301)	6.914 (1.127)	3.597 (–)
CHEM	7.349 (–)	– (–)	3.077 (–)	6.112 (3.302)	6.681 (2.180)
ENG	– (–)	– (–)	1.453 (0.380)	– (–)	2.803 (1.669)
MATH	– (–)	– (–)	– (–)	– (–)	2.456 (–)
PHYS	– (–)	– (–)	2.746 (2.724)	– (–)	3.928 (1.568)
SHS	– (–)	0.704 (0.697)	– (–)	– (–)	– (–)

Table 6
The patenting scores per permanent researcher performance of labs in classes and disciplines (mean values of *patent-perm* and standard errors in parentheses)

	Class 1	Class 2	Class 3	Class 4	Class 5
BIO	0.025 (0.559)	0 (–)	0 (–)	4 (–)	0.652 (.649)
MED	0.161 (0.308)	– (–)	0 (–)	0.383 (0.291)	– (–)
PHARMA	0.143 (–)	1.5 (–)	0.616 (0.651)	1.359 (0.975)	0.035 (–)
CHEM	0 (–)	– (–)	0 (–)	0.625 (0.883)	0.419 (0.382)
ENG	– (–)	– (–)	0.75 (1.061)	– (–)	0.382 (0.295)
MATH	– (–)	– (–)	– (–)	– (–)	0.063 (–)
PHYS	– (–)	– (–)	0 (–)	– (–)	0.146 (0.175)
SHS	– (–)	0 (–)	– (–)	– (–)	– (–)

Table 7
Description of the variables used in the multiple linear regression

Variable	Description
Perf-perm	Average publication performance of permanents in the lab
Perm-res	Number of permanent researchers (professors and full-time researchers)
PhD-pm	Number of PhD students per permanent researchers
Post-doc-av	Number of post-docs per permanent researchers
Non-res-pm	Number of non-researchers per permanent researchers
Promotion-pos	Share of promoted (holding senior positions) among permanent researchers
Full_1	Dummy variable, first quartile of the share of full-time among permanent researchers
Full_2	Dummy variable, second quartile of the share of full-time among permanent researchers
Full_3	Dummy variable, third quartile of the share of full-time among permanent researchers
Full_4	Dummy variable, fourth quartile of the share of full-time among permanent researchers
Age_1	Dummy variable, first quartile of the average age of permanent researchers
Age_2	Dummy variable, second quartile of the average age of permanent researchers
Age_3	Dummy variable, third quartile of the average age of permanent researchers
Age_4	Dummy variable, fourth quartile of the average age of permanent researchers
Patent-perm	Number of patent (applications) invented per permanent researchers of the lab
Pub-internat	Share of internationally co-authored publication occurrences among all publications of the lab
Pub-indus	Share of publications co-authored with industrial researchers among all publications of the lab
SHS	Dummy for human and social sciences
BMP	Dummy for biology, medicine and pharmacy
EMP	Dummy for engineering, mathematics and physics
CHEM	Dummy for chemistry

but it may usefully complement it by evidencing the main relations between per capita publication performance and other variables of interest that transcend the whole population. The variables used are described in Table 7 and the regression results are presented in the Table 8. Even if the regression exhibits a high goodness-of-fit score, these results should still be taken cautiously due to the limited number of observations.

Among independent variables, there is only one "size" variable, namely *per-res* which gives the number of permanent researchers. We find a significant and negative coefficient for that variable, suggesting small sized laboratories are more productive. This result is consistent with the results previously obtained in the literature (cf. Bonaccorsi and Daraio, 2002; Mairesse and Turner, 2002).

Concerning the age of the permanent researchers, the results are also consistent with the standard results in the literature. We find that only the third quartile of labs with respect to average age (Age_3) publish significantly more than the first quartile Age_1. Such result is compatible with an inversed-U shape of productivity according to age. Nevertheless, such result should still be taken cautiously since we only use cross-section data and that it is therefore difficult to distinguish between age and cohort effects (for a discussion on that issue see Stephan, 1996). The hypothesis of a potential effect of age mix on productivity has also been tested. Standard deviation of permanents' ages has been included in the regression. Nevertheless, it never appeared to be significantly related to publications. Since dropping it was increasing the fit of the model, we decided not to include it in the final regression.

Considering the professional status of the permanents, we find that the share of promoted among permanent researchers (*Promotion-pos*) significantly increases the publication performance of the labs. Two explanations may support the positive coefficient for promotion. The scientists who have the higher abilities for academic performance are likely to be the promoted ones (selection effect). Moreover, promotion may improve the professional status of scholars substantially, increasing their productivity just because they can better exploit unmeasured external resources (status effect) thus bringing in the labs some critical resources.

Table 8
OLS estimates of a multiple linear regression of the publication per permanent researcher performance of labs (*perf-perm*)

Dep var: perf-perm	Coefficient	Standard error
Perm-res	−0.036**	0.018
PhD-pm	0.274	0.618
Post-doc-av	0.511	0.410
Non-res-pm	1.401***	0.346
Promotion-pos	3.907**	1.579
Full_1	Ref.	
Full_2	1.502**	0.718
Full_3	1.319*	0.762
Full_4	0.879	0.831
Age_1	Ref.	
Age_2	1.059	0.770
Age_3	1.318*	0.714
Age_4	0.484	0.738
Patent-perm	1.300***	0.447
Pub-internat	−0.518	1.551
Pub-indus	−7.964	4.864
SHS	Ref.	
BMP	2.885***	1.076
EMP	2.495**	1.186
CHEM	3.480***	1.189354
Constant	−1.905	1.446547
Adjusted R2	0.5423	

NB: Standard errors are in parentheses. ***, ** and * indicate that coefficients are statistically significant at the 0.01, 0.05 and 0.10 levels, respectively. For the categorical variables, coefficient should be understood as compared with the first modality which is taken into reference (Full_1, Age_1 and SHS).

One important result is that it is only the second and (in a lesser extent) the third quartiles of labs according to the share of full-time among their permanents (*Full_2* and *Full_3*) that significantly publish more than the ones of the first quartile (*Full_1*). This tends to confirm the first insights of the typology indicating that it is by mixing together permanents that hold full-time research and teach-and-research positions that one may globally sustain publication productivity. The labs that have between 14 and 43% of the their permanents holding full-time positions (*Full_2* equals one), tend to publish even more than the labs that have higher share of full-time researchers.

The effects of non-permanent researchers and non-researchers have been recorded by using their ratios with respect to the number of permanent researchers: *Phd-pm*, *Post-doc-pm* and *Non-res-pm* are, respectively, the number of PhD students, the number of post-docs and the number of non-researchers per permanent researchers in the lab. Among these variables, only *Non-res-pm* appears to be significant. The non-researchers increase significantly the publication outcome of research laboratories.

As expected, laboratories disciplines affect significantly publication performance. We chose to have quite aggregated disciplinary dummies. The four-dummies configuration (see Table 8) has been retained since numerous iterations showed that it is the one that allows for the highest adjusted-R^2. We find that all disciplines publish more than the social and human sciences (SHS), with the highest coefficient recorded for chemistry (3.480). The disciplinary dummies essentially serve for control purposes since productivity naturally varies and SCI and SSCI covering are of unequal quality across fields.

7. Discussion and conclusion

This paper offers a first empirical investigation of an original dataset describing the research activity of a large European university which allows us to analyse the organization of research at the laboratory level. We study the labour force composition of labs, how these various inputs are correlated with the various outputs, and the output structure of the labs. Secondly, we construct a typology of labs, which identifies different styles of research organization and their outcomes. Finally, we run an econometric model to analyse the determinants of collective publication. The use of three different, but complementary empirical methods allows us to reach an important statement: labs have different organizations, which influence their scientific performance.

In the correlation studies we observe that full-time researchers are often associated to university professors who hold teach-and-research positions and that each type of permanent scientist attracts different kind of non-permanent researchers. PhDs appeared to be more intensively associated to university professors following primarily a logic of personal contacts and only secondarily a logic of excellence. The latter applies primarily to post-docs who are correlated with full-time scientists.

University professors tend to decrease all the scores in average outcomes. Concerning publication, this result seems to be induced by the presence of non-publishing university professors. We have no evidence of a distinctive behaviour between publishing professors and full-time researchers. The contribution of non-promoted permanent researchers is weak. The number of non-permanent researchers affects the distribution of outputs among the permanent researchers of the lab: PhDs and foreign post-docs increased with the kurtosis and the variance of the average publication performance of permanent researchers. That may indicate that they are attracted by some “publication stars” and/or that they work preferentially with the most productive researchers, thus specifically enhancing their productivity. Non-permanent researchers and especially French post-docs are important for the patenting activity of labs. Full-time researchers are the most important contributors to patent and publication production.

About the outcome structure, we found quite surprisingly that the share of international collaborations is not associated with a higher average publication performance. Those who collaborate more intensively with international co-authors are not necessarily those who publish more. On the contrary, the average performance in international collaborations goes along with a high performance in terms of collaborations with industrial partners. One important result is that the intensity of patenting activity is correlated with all publication intensity measures (both per permanent researcher): strongly with the intensity of publications with industrial partners and weakly with international partners. Moreover, while it grew over the period covered (1993–2000), the patenting activity seems to become more and more intensively linked to and supported by publication performance.

These first analyses of the combination of the different types of personnel in labs, of their contribution to the scientific production and of the correlation between outcomes led us to build a typology based on the simultaneous use of input and output variables. We obtained five classes of labs, which illustrate five different styles of research organization and production. A class (class 2) groups together all the labs belonging to the social sciences, geography and humanities and another (class 5) covers the “big” labs. The first class counts the highest share of full-time researchers, few non-permanent researchers, many non-researchers; they publish more than the average but patent much less than the average. In class 3 contrary to class 1 we find a high share of teach-and-research positions with many PhDs and non-promoted permanent researchers. This combination explains the low publication and patenting performances (cf. Section 4.3). Class 4 involves an equal share of full-time researchers and professors, permanent scientists are promoted and rather young, assisted by many non-permanent colleagues and working on an inter-disciplinary basis. This specific association generates the highest scores in terms of both patents and publications.

Finally we have complemented the typology and the correlation analyses by focusing on the determinants of the collective publication performances (using an OLS regression). Our most robust conclusions that are supported by the different analyses could be summarized as follows. Firstly, all methodologies used underline that the most publishing labs are also patenting. This tends to reject the crowding out hypothesis between publications and patenting. Nevertheless our study is not totally formally conclusive in that direction since we could not control for laboratory specific unobservable effects. Secondly, the mid-career promotion system in France appears as a consistent screening process since the share of promoted permanents always favour both publication and patent counts. Thirdly, we find that full-time and teach-and-research positions are complements since a “right” proportion (around an equal share) of both positions within labs induces a high performance in terms of publications. The presence of full-time researchers may contribute maintaining incentives for the university professors to perform research. This complementarity may also be due to their respective power of attractiveness: full-time researchers attract post-docs and university professors increase the number of PhD candidates. Such insight as well as several other complementary ones highlight the often ignored role of non-permanent researchers. This last result is certainly an important insight of our study to show that policy makers and managers of laboratories and universities should design strategies that explicitly take into account their ability to attract the growing population of non-permanent researchers. In the emerging European research space, the attractiveness of labs for young researchers, who constitute a highly motivated human resource, may well make the difference in terms of performance.

Acknowledgements

This work is part of a larger project on knowledge production at ULP developed by a team of researchers at BETA led by P. Llerena. We are grateful to him and to all other members of the team whose support was crucial at some points: Joaquin Azagra-Caro, Monique Flasaquier, Caroline Hussler, Rachel Levy, Thuc Uyen Nguyen Thi, Musa Topaloglu, Panos Vassiliadis, and Sandrine Wolff. Acknowledgements should be extended to the administrative departments of ULP, the technology transfer office (ULP-Industrie), and to the French patent office (INPI) for allowing us to get access to their databases. A. Bonaccorsi (Santa Anna School of Advanced Studies, Pisa) and F. Lissoni (CESPRI, Università Bocconi, Milano) should be acknowledged for their help in data collection. Thanks also to P. Roux who provided us technical assistance. A preliminary version of this paper was presented at the third EMAEE (European Meeting on Applied Evolutionary Economics) Conference “The Knowledge-Based Economies. New Challenges in Methodology, Theory and Policy”, Augsburg, Germany, April 10–12, 2003.

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