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The exploitation of complementarities in scientific production process at the laboratory level

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Abstract

The paper analyses the scientific research production of more than 80 laboratories belonging to Louis Pasteur University, a large and well-ranked European research university. We study research organisation of the labs focusing on the structure of research personnel and outcomes. The paper proposes a typology of laboratories, which enables us to stress different design for research organisation. The main results show how appropriate combinations of research personnel may strongly influence the publication and patent productivity.

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

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1. Introduction

This paper argues that the laboratory is the locus of many complementarities between researchers that should be taken into account to understand academic research organisation and production. In that respect, we depart from the literature in economics, which usually focuses on the individual level of analysis (Diamond, 1986; Levin and Stephan, 1991; Stephan, 1998). In the meantime, the literature recognises that complementarities are important to understand scientific productivity and scholars also repeatedly argue on the necessity to take into account the collective level of organisation and especially the laboratory level (Dasgupta and David, 1994; Stephan, 1996).

Nevertheless, there are only few economic empirical contributions devoted to the laboratory level of academic organisation. Joly and Mangematin (1996) build a typology of public laboratories based on three categories of variables: scientific production, type of funding and the research themes. They analyse the type of relationships each category of laboratory establishes with private partners. Laredo and Mustar (2000) develop a model for characterising the 'activity profiles' of labs based on their relative involvement in five different activities: production of certified knowledge, embodied knowledge, participation to competitive advantages, to public debates and involvement in the construction of public goods. Bonaccorsi and Daraio (2003) stress 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 is negatively correlated with productivity.

The originality of our study resides mainly in the attention devoted to the structure and characteristics of both laboratory personnel (status, age, full-time research or teach-and-research position, non-researchers, subdisciplines, etc.) and laboratory outcomes (publication counts and distribution, co-publication behaviour and patent counts). Our work is based on an original and unique database concerning the research activity of more than 80 scientific labs belonging to Louis Pasteur University (ULP) of Strasbourg and, covering more than a decade.

We show that permanent and non-permanent researchers are complements: Professors tend to attract Ph.D. students and post-docs choose labs with highly

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recognised full-time researchers. Moreover, we observe that the labs that patent more are also those that publish with industry and with international co-authors. Even if some permanent researchers (university professors and un-promoted permanents) are less productive than others (full-time scientists), complementarities between them exist: the shares of the categories of personnel affect their productivity. For instance, an equal share of professors and full-time scientists stimulates productivity.

The paper is organised as follows. In Section 2, we underline the added value of the laboratory level of analysis. Section 3 offers information on the data and some descriptive statistics. In Section 4, we develop a correlation study: between the variables characterising the labour force of the research laboratories, between patents and publications and finally between input and outcome indicators. Section 5 presents the typology, which identifies five 'styles of research production process' at the lab level. The last section discusses our main results.

2. Literature review and expected added value of analysing scientific production at the laboratory level

This section aims to illustrate how the laboratory level of analysis may contribute to enrich our knowledge on academic research production, taking into account the characteristics of the researchers (the type of position, their age, their discipline, etc.) and of the laboratory (size, scientific prestige etc.) and also the diversity of their outcomes. We argue that different types of complementarities exist and may be better grasped at the laboratory level: between different types of researchers (2.1), between the various outcomes (patents and publications) (2.2), reputation externalities (2.3) and size of laboratories (2.4). For each effect, we review the empirical literature and infer possible implications for our analysis.

2.1. Complementarities between different types of researchers: positions and age

The sociology of science questions whether research and teaching in academia are complementary or competitive activities at the individual level. 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). Fox (1992) used a survey based on a sample of social science faculties and showed that faculty members with high publication productivity exhibit strong interest in and commitment of time to research. They are not strongly involved in both activities, but favour research activities. Thus, her findings tend to prove that research and teaching are conflicting actions. If we follow her argumentation, it could be concluded that for productivity purposes it would be better to have full-time researchers instead of a majority of professorship positions.

In France, some scientists occupy full-time research positions and others are professors. At the laboratory level, it becomes interesting to analyse the advantages and shortages of each positions and to tackle the issue of a 'right proportion' of both types and of their complementarities. We will for instance show that university professors, generally less productive than full-time researchers, may enhance the productivity of the latter by driving Ph.D. students to them. This raises new questions in terms of access to non-permanent researchers (Ph.Ds and post-docs) and their impact on productivity. We will tackle this important issue, ignored by the specialised literature.

Some economists (Diamond, 1986; Levin and Stephan, 1991; Stephan, 1996; Weiss and Lillard, 1982; Zuckerman and Merton, 1972; Mairesse and Turner, 2002) focused on the publishing activity of scientists in life-cycle models, trying to explain the link between age and scientific production. They all show for various disciplines and scientists that publishing activity first increases, reaches a peak and declines.

At the laboratory level, the presence of different generations of scientists will probably induce collective effects. Thus, our investigation is no more related to the productivity trajectory over the life cycle but concerns the complementarities and reinforcing effects of researchers of different ages and the attractiveness of some labs. Bonaccorsi and Daraio (2003) develop this latter idea in their analysis of labs of the Italian National Research Council (CNR). They observe a negative relationship between productivity indicators and the average age of researchers. However, the average age of promoted permanents is not significantly related to productivity. According to them, the average age of researchers in a laboratory reflects its attractiveness and scientific vitality, following a virtual circle: Higher prestige institutions generally induce greater resource availability for young researcher positions and thus increases the attractiveness, etc.

2.2. Complementarities between outcomes

Stephan et al. (2002) 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 industry. Their main question was whether publications and patents were complements or substitutes. They first underlined that for the whole sample, less then 20% of scientists applied for at least one patent while 70% published at least one paper. 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 at the individual level.

At the laboratory level the question is no more related to the allocation of 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, where scholars may be specialised on different but complementary research agendas, which may or may not have a potential for patenting. For instance, the presence of non-permanent researchers appointed more specifically to patenting activity could partly explain a good performance of the lab in terms of publications and patents. Another issue concerns the management of research agendas having different time line. Finally, at the lab level it becomes interesting to analyse the link between patents and the type of co-authorship in publications. Does co-authorship with industry induce more patents?

2.3. Reputation externalities

Empirical studies in the USA found that researchers at prestigious university departments are more productive and are more cited than their colleagues in lower-ranked universities (Cole and Cole, 1973). The main questions concern the causality between productivity and department prestige and the relative importance of both effects. Long and McGinnis (1981) studying a population of biochemists in six organisational contexts show that the probability of being employed in a specific context is not strongly influenced by the publication productivity or the citations. But once employed in a specific environment, individual productivity soon conforms to the characteristics of that context[1]. Allison and Long (1990) analysed 179 job changes by scientists. The one moving to more prestigious places increased their rates of publication and of citation; those moving to less prestigious institutions showed substantial decreases in productivity: the departmental effect again seems to dominate. Mairesse and Turner (2002) found that the productivity of the CNRS research labs in physics and the quality of their publications influence positively the productivity of their researchers and the quality of their papers. Studying a set of university–industry collaborations between academic laboratories and firms in Europe and US, Carayol (2003) found that reputation and internal organisation of the laboratory may profoundly influence the nature of contractual funding from firms.

These results should allow us predicting the following outcome. In France, the prestigious labs are those affiliated to a public research organisation such as CNRS or INSERM. A peer review process taking into account the productivity of the lab operates such an affiliation. Affiliated labs benefit from increased monetary funds for research facilities, research positions and Ph.D. or post-doc grants. In other words, these labs should encourage scientific production and exhibit higher performances than the others. The nature of outcomes may also be affected at the laboratory level since, as Crow and Bozeman (1987) underlined, the nature of the research outcomes is strongly influenced by the funding structure of the laboratory.

2.4. Scale effects

Concerning size issues, the main question is related to the nature of scale returns of the production of scientific knowledge. One of the main problems lies in the possibility to assess all inputs used: The omission of one or more inputs could unduly lead to revealing decreasing returns. Adams and Griliches (1996) used data about US universities and found diminishing returns to the individual university R&D, for the total number of papers and for the total citations. Replacing R&D data by scientist ones induced higher coefficients on papers and citations, thus indicating measurement problems linked to the choice of input. In a subsequent paper (1998), 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 underline greater measurement errors at the individual level and the existence of spillovers, which may only be captured by an aggregate analysis. 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.

Given the greater measurement errors at lower level of aggregations, it will be difficult to analyse the nature of scale returns at the laboratory level. Usually results are much more basic. For instance, Bonaccorsi and Daraio (2003) found that size is never positively correlated with productivity; on the contrary in three domains 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. Arora et al. (1998) studying academic research at the laboratory level show 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

[1] Cf. also Long (1978).

respect to funding which approaches unity. Concerning the production of patents, the results seem to be slightly different. Wallmark (1997) and Henderson et al. (1998) showed that the largest research organisations apply for more patents. The question remains open and we will provide some results taking into account simultaneously patents and publications.

3. The data

The data concern the research activity of a 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: Medical Sciences, Mathematics, Computer Science, Physics, Chemistry, Life Sciences, Geology, Geophysics, Astronomy, Engineering Sciences. Human and social sciences are also present with 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 Nobel prizes.[2] Overall, ULP is one of the largest French universities in terms of research. The Third European Report on Science & Technology Indicators 2003 ranks ULP first among 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.

We will detail the structure of ULP by presenting the variables used in our study and the method employed to collect them. We collected data related to the personnel and the laboratories from internal administrative sources (cf. 3.1). Information related to publications came from the ISI Web of Science and the French Patent Office provided patent data (cf. 3.2). In each part, we will present the characteristics of our variables and the distribution of labs.

3.1. 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 standardised document, which is usually divided into two distinct parts: a précis of the past four years and, a project for the next four ones. The data cover 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. It operates through a peer review process mostly taking into account scientific production arguments and constitutes clearly a signal of the labs scientific excellence.

We gathered 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, the status (teach-and-research vs. full-time research positions), the grade ('promoted' stands for full-professor and Director of Research positions and 'un-promoted' stands for Assistant Professors and Researchers positions).[3]

We recorded 83 distinct laboratories in 1996. We have reliable and complete information for all, but two of them, for which we miss the complete characterisation 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,[4] 9 by INSERM, 31 by the Ministry of Research and by 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 year old. Among them, 360 are females (24.6%) and 57% occupy un-promoted positions. We also find some 1940 non-permanent researchers: 1230 Ph.D. students and 710 post-docs. Lastly, we recorded 1120 non-researchers (administrative staff and technicians) and 410 visitors.

ULP laboratories are rather small in terms of number of permanent researchers (61 labs have less than 20 permanent researchers); 8 labs declare more than

[2] In 1987, Jean-Marie Lehn was awarded for his contribution in supra-molecular chemistry. Ferdinand Braun obtained the Nobel prize in 1909 in physics for his radio telephone. Other Nobel prize winners spent some time in their careers at Strasbourg University.

[3] In France, promotion to full-professor and to Director of Research positions does not imply tenure: assistant professors and researchers are tenured from the very beginning of their career.

[4] 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.

41 scientists. The distribution for non-permanent researchers exhibits the same characteristics. For a large majority of labs (65%), more than 50% of permanent researchers occupy un-promoted positions. The average age of permanent scientists is above 50 in 70% of the labs, 5 labs have an average age between 40 and 45.

We also got the main scientific disciplines of the labs according to the specific categories defined by the university. These are the following: Astronomy (one lab), Biotechnology (12), Chemistry (9), Genetics and Cellular and Molecular Biology (9), Geography (2), Mathematics (1), Mechanics (1), Medicine (22), Odontology (1), Neurosciences (seven), Condensed Matter Physics and Chemistry (four), Subatomic Physics (two), Earth Sciences (two), Information Sciences and Technology (three), Humanities and Social Sciences (eight). To complement such information, we used data 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 normalisation 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 (the one of the National University Council). 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 8 in 2 laboratories.

3.2. The outcomes

Our database also integrates information about publications and patents. For each permanent researcher, we collected his published articles (using SCI, SSCI and Arts and Humanities ISI databases). More than 26,000 occurrences exist over the 1993–2000 period. This amount includes some double counting as some ULP researchers have co-authored papers. By dividing each occurrence by the number of co-authors, we obtain the effective (normalised) scientific contribution of each author (an author is necessarily a permanent researcher). 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 a non-French institution: 10,400 occurrences exhibit international co-authorship. Some co-publications are written with at least one co-author belonging to a firm: 1200 publications are co-authored with industrial partners, i.e. 4.6% of all publication occurrences.

Concerning the number of occurrences, 70 laboratories have published between 1 and 400 papers. The distribution is rather uniform in this interval. The distribution is much more dispersed for labs having published more than 401 papers (2 labs exhibit between 2001 and 3000 articles). Concerning the scientific performance, 67 laboratories have published between 1 and 100 papers, the distribution 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 is 2–4 articles per permanent researchers in 27 labs. 12 labs show an average of more than 8 papers. A small number of labs publish a large amount of papers. At the individual level, Lotka (1926) found that 6% of publishing scientists produced half of all papers.

The behaviour in terms of co-publication is rather contrasted: In 5 labs, the average number of co-authors is between 1 and 2 and in five other labs, the average is above 8. The mode is 5–6 co-authors in 30 laboratories. The distribution of international co-authorship is heterogeneous. In 9 laboratories, more than 50% of the publications are international; in 62 labs this percentage is less than 37.5. Ten laboratories never published with industry and at the other extreme 1 laboratory published between 25% and 30% of its papers with industrial partners.

The database also incorporates the French and European patents, which had been invented by at least one of the ULP permanent researchers. After a matching process between our data and the one provided by the French Patent Office (INPI), we found 850 occurrences of French or European patents granted. We eliminated the extensions of French to European patents and ended up with 463 patents invented by researchers from ULP. Some 189 patents were granted 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 data exhibit a decreasing relation between the number of laboratories and the number of patents obtained by a laboratory. Thirty-eight laboratories have no patent, 31 laboratories have between 1 and 10 patents, 5 laboratories have between 11 and 20 patents and 1 lab obtained between 51 and 60 patents.

4. Opening the black box of academic laboratories

In this section we analyse correlations between laboratory inputs and outputs. The main objective is to underline existing complementarities between the different research personnel on the one side, and between the various outcomes on the other side. In other words, we characterise the organisation of labs taking into account the diversity of scientists' grade and their contribution to the productivity of the lab. We also present the publishing and patenting patterns of the labs.

Correlation results are presented in three steps. Input–input correlations describe how labs are organised in terms of their personnel. Input–output correlations provide information about how each type of scientist contribute to publications and patents. Finally, we study output–output correlations in order to have a first hand investigation about whether the patents and publications are complements or supplements. We also analyse how international and industrial publications correlate with patents. For clarity and length reasons, we will not present the results of the correlations[5] concerning disciplinary specificities, sex, interdisciplinarity or institutional recognition.

4.1. The personnel design of laboratories

In this part, we show that permanent and non-permanent researchers are complements; university professors are primarily linked to Ph.D. students via previous contacts and highly recognised full-time scientists attract post-docs. We also point up a linear allocation of non-researchers and permanent researchers in the different labs.

4.1.1. Strong correlations between permanent and non-permanent researchers

When analysing the structure of the personnel, one may wonder whether permanent and non-permanent researchers are complements or substitutes. In the support of the former hypothesis, we find that the number of permanent researchers and the total non-permanent researchers are significantly correlated.

At a more disaggregated level, the underlying association of permanent and non-permanent researchers within labs is more complex. Ph.D. students are primarily correlated with professors. Nevertheless, they are also strongly correlated with full-time researchers. This result does not necessarily mean that full-time researchers often supervise Ph.Ds. It could be due to the fact that full-time researchers are mainly located in the most recognised labs, which may provide more grants, thus attracting more Ph.Ds. That observation seems to be supported by the fact that Ph.Ds are negatively correlated with the labs, which are not funded by the large national funding agencies. The latter are merely supported by the Ministry of Research and involve only a few full-time permanent researchers. Thus, Ph.D. 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 full-time researchers and high institutional recognition. They are not correlated with university professors while at least a small but significant correlation would have been expected. This result could give some support to the 'attractiveness' hypothesis developed by Bonaccorsi and Daraio (2003) for post-doc positions, which could be considered as pre-recruitment situations.

4.1.2. Regular allocation of non-researchers and permanent researchers

The non-researcher personnel are strongly correlated with full-time researchers and with non-permanent researchers. Their allocation seems to be also very dependent on the disciplinary environment. Non-researchers are correlated with Subatomic Physics and Genetics and Cellular and Molecular Biology, which require heavy instrumentation and many technicians and engineers. One may observe that the presence of non-researchers is not significantly correlated with any variable characterising 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.

Average age is only correlated with Medicine. This probably indicates a specific long-lasting training in that domain. Moreover, the share of un-promoted positions among permanent researchers is not correlated with any other variables. These observations tend to indicate that the arrival of researchers in labs probably followed uniform global trends without being affected by any of our variables. For instance, neither the size of laboratories nor their institutional recognition or their disciplines seem to have modified the arrival of permanent researchers in labs. Again the hypothesis of a linear and regular allocation[6] of personnel in labs would hold for scientists. Such results also show that the laboratories housing older permanent researchers are not necessarily the most recognised (institutional recognition is not correlated with average age).

[5] The reader may refer to a companion paper (Carayol and Matt, 2003) where these correlation coefficients are presented and commented.

[6] Bonaccorsi and Daraio (2003) found that allocation of researchers followed a waveform dynamics.

4.2. Personnel contributions to the laboratories production

The aim of this part is to study the connections between the various outcomes of research and the characteristics of different types of personnel. We first examine the contrasted contributions of university professors and full-time researchers. Next, we tackle the positions and age issues. Last, we turn toward the important effect of non-permanent researchers.

4.2.1. University professors vs. full-time researchers

One main and probably not so surprising observation concerns the publication productivity of university professors. The correlation between publication performance per permanent researcher and university professor is negative. Moreover, university professors are negatively correlated with the share of authors among permanent researchers 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 full-time 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.

Full-time researchers are strongly correlated with the number of publication occurrences and with the publication performance. They have strong connections with the international scientific community (correlated with the share of international collaborations among all publication occurrence). A scale issue seems to appear since this share is correlated with the number of permanent researchers and the number of non-researchers. 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 full-time 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.

Full-time researchers are the most important contributors to patent production. A possible scale effect may exist, since we observe that full-time researchers and Ph.Ds are also correlated with the increase rate in patenting activity. University professors are not significantly correlated with patent production. But, they are positively correlated with an increase in patenting and with a move from non-patenting to patenting between the two sub-periods, which may indicate a change in behaviour.

4.2.2. Age and promotion of permanents

Publication performance is strongly negatively correlated with un-promoted permanent researchers while it is not significantly correlated with age. Several complementary explanations may be provided. Some un-promoted scientists may probably stay un-promoted due to their lower research abilities or publication incentives. This result may also be partially obtained because a high share of un-promoted researchers occupy Assistant Professor positions, combining teaching, research and administrative activities.

The share of publications written with at least one industrial partner is negatively correlated with un-promoted permanents and university professors. They both seem to be more oriented toward the scientific community. They are also the least productive ones and thus, 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. The number of international publications is neither correlated with university professors, nor with un-promoted permanents.

4.2.3. The importance of non-permanent researchers

Non-permanent researchers affect the publication performance among authors within labs: The variance of publication performance is correlated with foreign post-docs. Moreover Ph.Ds and foreign post-docs are strongly correlated with the kurtosis of scientific performance distributions among authors. These results seem to indicate that hosting 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 highly productive researchers. These explanations could in some ways be supported by the high correlation between the kurtosis of the number of co-authors and the Ph.Ds and foreign post-docs, 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). The French post-docs are correlated with the patenting productivity of permanent researchers. 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.

4.3. Outcomes structure

We first emphasise that the labs, which publish more are more open toward industry but not toward international co-authors. We also highlight a reinforcing effect between patents and all types of publications (publications in general, but also with industry or with international co-authors).

4.3.1. International and industrial publications

The share of publications with foreign institutions among all publications is not correlated with the publication performance per permanent researcher apparently indicating that the labs, which have more international collaborations, 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, 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 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: international publications per permanent researcher and industrial collaborations per permanent researcher are positively correlated. That may express the fact that internationally visible scientific labs tend to attract more firms.

4.3.2. Publication and patenting performances

The data strongly support that pure scientific productivity and invention appear to be complements: the publication performance per permanent researcher is strongly correlated with the patents per permanent researcher. The result is also true when looking at the correlation with patents per researcher, even if less strongly. Since the increase in patenting is strongly correlated with the whole publication performance there may be a scale effect here. Our results seem thus to confirm the findings of Stephan et al. (2002) (cf. 2.2).

Patents per permanent researcher and patents per researcher are even more strongly correlated with industry collaborations. The causality seems to go this way since the rate of increase in patenting between the two sub-periods is strongly correlated with the industry collaboration. The intensity of publication 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.

Complementarity is also observed in the case of international collaborations: The rates of increase in patenting and international publication occurrences are correlated. 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. 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 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. Different scientific production design

We now turn toward a deeper analysis that would allow us to identify various ‘styles of research production’ at the lab level. There are obviously different ways to associate inputs in labs that generate different amounts of the two types of outcomes. To do so we build a typology of laboratories following a standard methodology composed of a multi-correspondence analysis (MCA) followed by an ascendant hierarchical classification (AHC).

The variables used for building the typology are the following. (i) inputs: full-time researchers, university professors, share of un-promoted among permanent researchers, average age of permanent researchers, subdisciplinary entropy of permanent researchers,[7] national post-docs, foreign post-docs, non-researchers, institutional recognition; (ii) outcomes: publication performance per permanent researcher, patents per perma-

[7] The interdisciplinarity entropy index records on a unique scale how flat the distribution of the researchers over the whole set of sub-disciplines is. Such a diversity index is defined as follows: $-\Sigma_{i\in j}\ ((n_{ij}/N_j)\ln(n_{ij}/N_j))$ with n_{ij} the number of permanent researchers belonging to lab j who are associated with sub-discipline i, and N_j the total number of permanent researchers belonging to lab j.

nent researcher, share of authors among permanent researchers, variance of publication performance among authors, share of industrial collaboration among publication occurrences and share of international collaborations among publication occurrences. These variables were transformed into qualitative variables with three modalities: low, medium and high. Only institutional recognition, the shares of international and industrial collaborations among publications are transformed into dichotomised variables. The typology is built for the 81 labs about which we have complete information on the above-mentioned variables of interest.

Five coherent classes of labs were selected because with these five ones, the within-classes share of the total variance was nearly 44.7%, which is usually admitted as a good ratio (cf. Benzécri, 1992). One class groups 10 laboratories, all belonging to the fields of social and human sciences (while no variable directly related to the disciplines were used for building the typology): These labs have obviously common and specific features (low size, low productivity, no patents, etc.). One other class groups together the largest 22 laboratories: high scores in the size variables used for the typology mainly explain such result.

In what follows we concentrate on the remaining three classes, the comparisons of which appears to be the most interesting. Our results are based on the opposition of the classes on the four axes retained in the MCA and on descriptive statistics. Both are not presented here due to space constraints but can be produced upon request (some details and technicalities can also be found in Carayol and Matt, 2003).

5.1. *The standard research-intensive labs*

The 22 laboratories of this class are of a rather small size and ‘research intensive’, since they count a high share of full-time researchers as compared to university professors. They host only few Ph.Ds and 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 their small size), their entropy index is the lowest. The average age of permanent researchers is higher than average. Moreover, the share of un-promoted positions lies below average, which may indicate on average higher academic recognition of these permanent researchers.

The scientific performance of these labs is higher than the average labs, with 5.96 papers written (in individual contribution) per permanent researcher. The papers are written on a less international basis on average even if permanent researchers have written on average as many internationally co-authored papers as average. The collaboration with industry is below the average. This may help explain that permanent researchers produce on average only 0.12 patents (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 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 recognised labs and half of the labs supported by INSERM. This observation led us to compare the characteristics of the highly recognised ones with the other ones. The two noticeable differences were that the recognised 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.

5.2. *The non-research intensive and industry-oriented labs*

This class 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 Ph.Ds 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 un-promoted positions represent 70% of the permanent positions.

The ratio of authors among permanent researchers and the publication performance of authors is also 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 patents 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 in Biology, in Physics related fields, Engineering, Medicine and one in Chemistry and in Neurobiology. Nearly half of the labs are supported by the CNRS.

5.3. *The elite research-intensive labs*

The 12 labs of this class are of a small size even if slightly bigger than the ones of the first class and smaller than the ones of the second. The share of full-time researchers among permanent researchers is slightly below average. The share of un-promoted permanents and their 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 Ph.D. students (nearly as many as in the second class but with much fewer professors), twice as many national post-docs and more than three times as many foreign post-docs than in the first class. With the same number of sub-disciplines as average, the sub-disciplinary entropy is the highest (0.9) but never very high (max 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 more paper more than the authors of the first class (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 produce patents (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 belong to Bio-Pharmacy, two to Chemistry and one to Biology.

6. Discussion and conclusion

This paper offers a first empirical investigation of an original set of data describing the research activity of a large European university. Such dataset allows us to analyse the organisation of research at laboratory level. We examine the labour force composition of labs and its influence on various outcomes. We also study the output structure of labs in order to stress possible complementarities or crowding out between outputs. Finally, the typology of labs highlights different types of research production processes or design.

As expected, we find collective effects on research production at the laboratory level. There are complementarities between different types of research personnel: appropriate combination of different types of research personnel has significant impact on the research productivity of the lab. An equal share of full-time researchers and professors maintains incentives for the latter to perform research. Moreover, there are specific links between permanent and non-permanent researchers. Full-time researchers increase the research performance of the lab and attract post-docs. Even if university professors decrease all the scores in average outcomes, they increase the number of Ph.D. candidates thanks to previous contacts. Moreover, our results highlight the often ignored impact of non-permanent researchers. Especially, national post-docs increase significantly the average number of patents invented by permanent researchers. This result could indicate that such post-docs are dedicated to invention activities which may be explained either by the their weak autonomy in research agenda selection or by their early involvement in a career path turned toward research in industry.

Another added value of our study comes from analysing the outcome structure of the labs. We find 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: strongly with the intensity of publications with industrial partners and weakly with international co-authors.

These results are summed up and combined in the typology which highlights the various designs for academic research organisation and production. We find that one class of labs exhibits performance scores which contrasts with other comparable ones: while their permanent researchers publish even more than the standard research-intensive labs, they also patent over eight times more. Such high performance is due to an interesting combination of personnel: The presence of younger and promoted permanent researchers, equally allocated between full-time researchers and university professors, focused on various sub-fields, allows to attract both many Ph.D. students and post-docs.

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