Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Information Economics and Policy 18 (2006) 55–72
INFORMATION ECONOMICS AND POLICY
www.elsevier.com/locate/iep

Individual and collective determinants of academic scientists' productivity

Nicolas Carayol, Mireille Matt *

BETA, UMR CNRS 7522, Université Louis Pasteur, 61 Avenue de la Forêt-Noire, 67085 Strasbourg, France

Received 19 January 2005; accepted 28 September 2005
Available online 15 December 2005

Abstract

The paper analyses the scientific research production of more than a thousand faculty members of Louis Pasteur University, large and well ranked in Europe. We take account of individual and collective determinants to explain individual productivity in terms of intensity and quality. We find that individual variables related to the position occupied are significant. The size of the lab plays negatively on performance. The intensity and quality of colleagues' research activities in labs are beneficial for individual research. Public contractual funding is the only type of funding which affects research intensity. Individual research production figures are significantly enhanced by the presence of foreign post-docs.

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

Keywords: Economics of science; Academic research productivity; Laboratory

1. Introduction

Academic research activity is increasingly viewed as an important contributor to the production of knowledge and thus to innovation and growth. Over the last twenty years, a significant amount of work has been dedicated to analyzing the impacts of public research results on economic activity (cf. Salter and Martin, 2001). Economic scholars have examined

* Corresponding author. Tel.: +33 390242102; fax: +33 3902420710.
E-mail address: matt@cournot.u-strasbg.fr (M. Matt).

0167-6245/$ - see front matter
doi:10.1016/j.infoecopol.2005.09.002

how firms use the knowledge produced by public research organizations (Cohen et al., 2002), which types of firms exhibit a higher propensity to draw upon public research results (Mohnen and Hoareau, 2002; Fontana et al., 2004), and the channels used by both types of actors to interact (Meyer-Krahmer and Schmoch, 1998; Cohen et al., 2002). Even if some economists have analyzed the potential benefits and drawbacks of university–industry partnerships for universities (Poyago-Theotoky et al., 2002; Stephan, 2001), the internal organization of public research entities is still far from having received enough attention from economists in spite of some major theoretical (Dasgupta and David, 1994) and empirical contributions (for a survey see, Stephan, 1996).[1] In brief, there is room for setting a research agenda aiming to open the 'black box' of the production process of scientific knowledge.

Such a lack of a sufficient level of economic analysis concerning the organization of scientific activities (and its effects on performances) is even more surprising when compared to the huge effort devoted by economists to understanding the innovation process, its industrial organization and its efficiency. The questions asked by this extensive literature on innovation could to some extent be adapted to the organization of science: Why should interaction and interactivity matter in innovation and not in science? Why should size be of importance for firms' performances and not for academic ones? The deeper economic understanding of innovation has motivated new policy debates and instruments (aiming to stimulate interactions between various actors, to sustain SMEs, etc.). We contend that a deeper understanding of science could induce the economists to revisit the rationales for science policies. Questions related to the effects of the size of the laboratories, their composition in terms of research personnel, and the type of funding on their performances become especially relevant in a context of budgetary shortening.

The aim of this paper is to analyze the productivity of individual academic researchers taking into account both personal features and the characteristics of the laboratory in which the researcher is active. We argue that the laboratory is the locus of many interactions and that complementarities between researchers should be taken into account to explain and understand the productivity of individual researchers. Our approach is rooted in an industrial organization perspective rather than in a labor market one like most economists of science.

On the one side, this paper is based on results obtained in previous research (Carayol and Matt, 2003a,b), which tend to highlight the laboratory as a relevant unit for academic research analysis. Therein we study the organization of research laboratories of a large French university (Louis Pasteur University, Strasbourg). We show that the interaction of different types of research personnel (full-time-research versus teach-and-research positions) has a significant impact on the research productivity of the lab. We also underline the often-ignored positive effects of non-permanent researchers (post-docs and PhD students). It seems that associating young and promoted permanent researchers, equally allocated between full-time researchers and university professors, focusing on various sub-fields, in small sized labs induces high performances in publication and patenting activity.

On the other side, we take into consideration various results derived by economists and sociologists of science, who generally focus on the individual productivity of researchers. Approaches based on life-cycle models (Diamond, 1986; Levin and Stephan, 1991;

[1] One should mention the trend of empirical research dedicated to the community of economists initiated by G. Stigler (cf. Stigler and Friedland, 1975) which is still active (see for instance Ellison, 2002; Laband and Tollison, 2003). See also Frey (2003) and Riyanto and Yetkiner (2002) or for more normative approaches.

Stephan, 1998) find some age–publication relationships, but with a low explanatory power (Stephan, 1996). This statement suggests the necessity to take into account other information on scholars themselves, such as their positions (Fox, 1992). It also suggests considering the collective level of organization, such as the reputation of university departments (Cole and Cole, 1973), the size of the laboratory (Bonaccorsi and Daraio, 2002), the quality of colleagues' publications (Mairesse and Turner, 2002), etc.

The originality of our approach is thus to combine both individual and collective determinants to explain individual research productivity. At the individual level, beside age we hold information about the type of position occupied (full-time research versus teach-and-research positions) and whether mid-career promotion is obtained (from Researcher to Director of Research, and from Assistant Professor to Full Professor). The collective variables include the ages of the colleagues, their positions, and the number of non-permanent researchers, non-researchers, and funding variables. Our work is based upon a unique database concerning the research activity of more than eleven hundred permanent researchers active in more than eighty scientific labs of Louis Pasteur University (ULP) of Strasbourg and, covering more than a decade.

We find that individual variables related to the positions occupied and to the promotion are significant while age only becomes significant when the threshold between publishing or not receives a specific treatment (in a Tobit regression). The size of the lab plays negatively on performance. The intensity and the quality of colleagues' research activity in labs are mainly beneficial for individual research productivity. Public contractual funding is the only type of funding which affects research intensity. Foreign post-docs significantly enhance individual research quality.

The paper is organized as follows. In Section 2, we propose the literature review of the individual and collective determinants of publication productivity. Section 3 provides information on the data and presents the methodology. The regression results are to be found in Section 4. The last section discusses our main results.

2. Individual and collective determinants of academic productivity: literature review

This section reviews the potential individual (2.1) and collective (2.2) determinants of individual research productivity that we will use in our regression. For each factor, we present the main results found in the literature, we explain how we may take them into account in the French institutional context of our analysis and we propose some expected effects.

2.1. Individual effects

In economic literature, individual productivity is usually explained by a set of variables related to the same topic. For instance, some scholars analyse the effects of age on individual productivity, others question whether the type of position is of importance, disciplinary and gender issues are also discussed. Except gender, we intend to integrate all of them in our regression analysis. The review of the literature should help us to predict how the variables should influence productivity.

2.1.1. Age

Economists and sociologists strongly highlighted and studied the impact of age on scientific productivity. Lehman (1953) first provided some evidence that scientists' major findings occur in their 30s or 40s. Later he showed that the creativity peak occurred earlier in more fundamental disciplines while it occurred later in empirically based ones (Lehman, 1958, 1960). He also found that the age peak is sharper for major contributions.

Zuckerman and Merton (1972) provided anecdotal evidence and an analytical framework for such an inverted-U shape of academic scientists productivity. Cole (1979) realized a systematic empirical analysis and found a single peak curve on six fields with cross section data. Longitudinal evidence on one field (mathematics) allowed him to distinguish between age and cohort effects, thus confirming the hypothesis. Pelz and Andrews (1976) and Bayer and Dutton (1977) obtained a two peak (around 30–40 and around 50 years of age) productivity curve.

Economists have tried to explain academic scientific production using standard human capital theory, the accumulated stock of knowledge in human capital a priori being a critical production factor of further knowledge production. Following such a theory, the evolution of scientists' productivity is essentially explained by efforts dedicated to human capital accumulation. Because the expected returns of human capital investments are decreasing with the remaining activity period, a decrease of research production through the life cycle is predicted (McDowell, 1982; Diamond, 1984). Several empirical studies using panel data of publication profiles have tried to corroborate this prediction. Diamond (1986) showed that such a decrease occurred in the publication profiles of Berkeley University mathematicians. Nevertheless, one may argue that the scientific production process within such a discipline is quite specific. Indeed, the studies of Weiss and Lillard (1982) and Levin and Stephan (1991) showed that in most fields researchers' productions tend to increase in the early career, reach a peak and then decrease.

As mentioned in Section 1, these human capital models have a low explanatory power, probably due to the fact that other variables explain the publication behavior of academic scholars. Variables such as their positions and reputations (i.e., their promotion) may play an explanatory role. As suggested in Zuckerman and Merton (1972), Knorr et al. (1979) showed that scholars progressively turn toward research administration tasks as they get older and productivity declines. They found that when one controls for supervisory tasks, the age becomes non significant. The question concerning the existence of an age-publication relationship, when controlling for other variables is addressed in this paper.

2.1.2. Types of positions occupied by scholars

The sociology of science studies whether research and teaching in academia are complementary or competing 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 faculty and showed that faculty members with high publication productivity exhibit a strong interest in and commitment of time to research. They are not strongly involved in both activities, but favor research activities. Thus, her findings tend to prove that research and teaching are conflicting actions.

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[2] or INSERM.[3] Nevertheless both categories work together in the university labs.[4] If we follow the argumentation of Fox, we could expect that individual productivity will be enhanced if scientists occupy a full-time research position.

In addition, for both categories, there is a clear promotion (from Assistant Professor to Full Professor; or from Researchers to Director 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.

The expected effects of promotion are ambiguous. On the one hand, since promotion implies increases in wage and social status, there are important incentives for exerting efforts before promotion while incentives are reduced once the promotion is obtained. Thus there is a dis-incentive effect of promotion. On the other hand, two other phenomena suggest a positive coefficient for promotion. The scientists that 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 external resources (status effect). Waldman (1990) suggested such an effect for tenured (vs. non-tenured) positions.

2.1.3. Scientific disciplines

It is a very classical insight from scientometrics that publishing activity and citation practices vary considerably from one discipline to another. Thus for control purposes it is important to prove such differences. One may also wonder whether there may be an interaction between age and discipline: For instance it is known that the peak in scientific activity occurs at different ages depending on the disciplines considered (Weiss and Lillard, 1982; Levin and Stephan, 1991). Thus, an age–discipline cross-effect should be at least tested in regressions to check whether scientists' productivity is linked to a specific age–discipline relation.

2.2. Laboratory effects

Contrary to the sociologists of science, the economists considered only very recently the collective variables as explanatory factors of individual productivity. We will thus use the results of both types of the literature to define the potential determinants. These different approaches (including our own results developed in previous papers (Carayol and Matt, 2003a,b)) indicate that the composition of the laboratory in terms of average age of scholars, proportion of full-time versus non full-time researchers, of promoted versus non-promoted colleagues, but also the quality of the colleagues' publications and, the prestige and the size of the lab may influence scientific productivity.

---

[2] "Centre National de la Recherche Scientifique", National Institute for Scientific Research.

[3] "Institut National de la Santé et de la Recherche Médicale", National Institute for Health and Medical Research.

[4] 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.

2.2.1. The average age and the positions of colleagues

While the literature concentrates on the impact of scholars' ages on their own productivity, one may wonder whether, at the laboratory level, the presence of different generations of scientists would induce collective effects. Here, the issue is no more related to the productivity trajectory over the life cycle but concerns the complementarities between researchers of different ages and the attractiveness of 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 permanent staff 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 increase the attractiveness, etc.

Similarly, the types of positions occupied by close colleagues within labs may also influence individual productivity. We may for instance wonder whether the presence of a high share of full-time researchers (vs. university professors) enhances productivity or not. We may also wonder whether the share of promoted colleagues improves individual productivity just because they provide better advice or contacts.

2.2.2. The quality of institutions and colleagues: Productivity externalities

Empirical studies on US data found that researchers at prestigious university departments are more productive and more often cited than their colleagues in lower-ranked universities as Cole and Cole (1973) showed on a sample of 120 physicists. Hansen et al. (1978) found that the quality of the universities is the critical variable for explaining future production. Cole (1970) suggested that the reputation of the hosting institution generally signals researchers' abilities, enabling them both to raise funds more efficiently and to diffuse their results in the scientific community more widely and quickly.

One of the main questions concerns the real determinants of productivity: Is it due to intrinsic abilities or to a 'departmental effect'. Long and McGinnis (1981), studying a population of biochemists in six organizational 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.[5] Allison and Long (1990) analyzed 179 job changes by scientists. The ones 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.

When one goes beyond the university or the department level, it becomes relevant to address the question of the scientific activity and quality of colleagues. Mairesse and Turner (2002) studying the publishing activity of a sample of French CNRS full-time researchers in the field of Condensed Matter found that the productivity of colleagues weakly influences the researchers' own production while their quality (proxied by the average Impact Factor of their publications) strongly matters for the average quality of their own papers.

[5] cf. also Long (1978).

2.2.3. Non-permanent researchers

The importance of non-permanent researchers on permanent ones productivity is mostly ignored by the specialized literature. Carayol and Matt (2003a,b) emphasized this point through qualitative data analysis using the same sample as in this paper. They found that within labs, non-permanent researchers significantly affect the per permanent researcher outputs: Foreign post-docs are correlated with publication activity while national ones match high patent production. This raises new questions in terms of access to non-permanent researchers (PhDs and post-docs) and their impact on permanent researchers' productivity.

2.2.4. Size issues

Concerning size issues, the first 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 data on R&D by data on scientists' induced higher coefficients on papers and citations, thus indicating measurement problems linked to the choice of input. In a subsequent paper Adams and Griliches (1998) showed that at an aggregate level, the research production follows constant returns to scale; 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.

Given the greater measurement errors at a lower level of aggregation, it becomes difficult to compute returns to scale at the laboratory level. Usually results are much more basic and lab size issue is addressed as approximated by the number of permanent researchers. For instance, Bonaccorsi and Daraio (2003) found that size measured this way 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. Carayol and Matt (2003a,b) revealed similar results. In this paper, the question arises whether from an individual point of view it is better to carry out research in a smaller or a larger structure.

2.2.5. Funding

The nature of outcomes may 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. In this respect, the types and the sources of funding may become critical.

Concerning the former issue, there may be some differences between recurrent traditional national funding in Europe and funding provided through competitive and open procedures as it is more often the case for US federal funding of academic research. Arora et al. (1998) studied the effects of the contractual funding by the CNR research program on Italian academic research teams. They showed that (even if relying on cross section data) there are decreasing returns of funding on "quality adjusted" publications while the most reputed teams reveal an elasticity of scientific performance with respect to funding which approaches unity. Based on the same-but-extended dataset, Cesaroni and Gambardella (2003) find constant returns to scale for such funding.

The source of funding may also be of some importance. Studying a set of university-industry collaborations between academic laboratories and firms in Europe and the US, Carayol (2003) shows that reputation and internal organization of the laboratory might profoundly influence the nature of contractual funding provided by firms. Based on the same dataset as ours, Boumahdi et al. (2003) study the determinants of private contractual funding of academic laboratories. This analysis concludes that public contractual funding crowds out private one, that research quality tends to diminish the fit of the match, and that post-docs enhance it.

3. The data and methodology

In a first step (Section 3.1), we present our data collection and our data set. The review of the literature allowed us to justify the choice of our determinants, we now introduce the variables selected at the individual (Section 3.2) and at the lab level (Section 3.3). Finally, we present the methodology used (Section 3.3).

3.1. Data set

The data concern the research activity between 1993 and 2000 of a single university: Louis Pasteur University (ULP) of Strasbourg (France). 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. 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. Active researchers count one Nobel laureate, eleven members of the Institut Universitaire de France and eleven members of the French National Academy of Science. Such research capacity arises from a close-knit with the major national research bodies such as the National Center for Scientific Research (CNRS) and the National Institute for Health and Medical Research (INSERM) present in the Strasbourg area.

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: 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, which represent, respectively, what was achieved during the four-year periods before and after 1996 (i.e., the new affiliation contract). 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.

3.2. Individual researchers

1460 permanent researchers were reported in these documents: They were all present in 1996. A similar document exits for the 2001–2004 period. Thus we had information about which permanent researchers were still present in the university in 2000. We excluded all permanent ones that were not on that list in order to be sure that none moved to another university or retired. At the end of the process, 1134 permanents remained.

We collected the published articles of each permanent researcher in our database (using SCI, SSCI and Arts and Humanities ISI databases). More than 26,000 occurrences exist over the 1993–2000 period. We matched this table with our restricted list of 1134 permanents and kept only the occurrences that were published over the period 1995–2000 for which we are nearly sure they were still employed by the university. 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 (normalized) scientific contribution of each author considered (an author is necessarily a permanent researcher). The variable *Pub.perf* gives the publication performance of each permanent researcher (and corrects for co-authorship). The variable *Pub.imp* weights in addition each item by the impact factor (given in ISI-JCI). It gives thus the individual publication performance corrected for impact over the same period. *Pub.perf* and *Pub.imp* represent the two dependent variables.

For each permanent we have reliable information concerning:

- Their ages. The variable *Age* gives the individual age in year 1996.
- Their professional statuses in 1996. It covers two dimensions. First, they may have either non full-time or full-time research positions. Second, the dummy variable *Full-time* indicates whether the permanent researcher has a full-time research position. The permanent researchers may also be 'promoted' as Full Professors or as Directors of Research or may still be 'un-promoted' as Assistant Professors or Researchers. The dummy variable *Junior* indicates non-promotion in 1996.[6]
- Their scientific disciplines. In what follows we use the more aggregated level. The variable *Discipline* has eight modalities: First is Mathematics, second is Physics, third stands for Chemistry, fifth is Engineering Sciences, sixth is Biology, seventh is Medicine and the last one stands for Social Sciences and Humanities.

3.3. Laboratories variables

We recorded 79 distinct laboratories in 1996 for which we have complete and reliable information, especially concerning the permanent personnel. We are thus able to attach to each individual scientist the variables characterizing their labs. The variables we have selected correspond to proxies expressing successively the size of the lab, the ages and the positions of the colleagues, their productivity and quality, the presence of non-permanent researchers and the funding sources.

[6] We were able to know whether the status had evolved between 1996 and 2000. Since we found only 11 promotions over the whole population, we do not include that dimension in the analysis.

The number of permanent researchers (*Lab.perm)* embodies our single laboratory size variable. All other quantities relating to the lab will be given in shares if directly connected to permanent researchers, and per permanent researcher otherwise.

To compute the characteristics of the permanent colleagues, we take into account all the permanent researchers of the lab and exclude the researcher who is analyzed. *Lab.age* gives the average age of the permanent colleagues. *Lab.junior* and *Lab.fulltime* express the shares, respectively, of juniors and full-time researchers among colleagues.

The productivity of colleagues over the 1993–2000 period is approximated by *Lab.Pubperf*, which corresponds to the average publication performance of colleagues, corrected for co-authorship. The quality of colleagues' publications is proxied by *Lab.Pubimp*, which corresponds to the average publication performance of colleagues, corrected for co-authorship and for impact.

We also include data on all types of personnel, which are often not included in empirical analyses: Some 1,230 PhD students, 710 post-docs and 1120 non-researchers (administrative staff and technicians) were reported in year 1996. The variables *Lab.phd*, *Lab.postdocN*, *Lab.postdocF* and *Lab.nonres* stand, respectively, for the number of PhDs, of national post-docs, of foreign post-docs and of non-researchers.

Lastly, we were able to collect precise information about funding of the laboratories (excluding wages). We have data on regular public funding for the period 1996–2000. The variable *Lab.funding* gives the amount per permanent researcher. We also collected information about the contractual funding over the whole 1993–2000 period. The latter was decomposed by source of funding: Public funding at the European, national and local levels, and private ones. The variable *Lab.contractualPub* corresponds to the amount of contractual public support per permanent while *Lab.contractualPriv* stands for private support. Table 1 provides the statistics for the individual and collective variables.

4. Methodology

We first use a simple linear regression OLS model of the form:

$$Y_i = X'_{1,i}\beta_1 + X'_{2,i}\beta_2 + \varepsilon_i \tag{1}$$

with Y_i standing for the dependent variable which may be either *Pub.perf* or *Pub.imp.* The vectors $X_{1,i}$ *and* $X_{2,i}$ stand, respectively, for the individual and collective independent variables. β_1 and β_2 are their associated vectors of coefficients. The vector ε of the error terms ε_i is such that: $E(\varepsilon) = 0$, $E(\varepsilon\varepsilon') = \sigma^2 I$, and $E(\varepsilon|X_1,X_2) = 0$.[7] The two sets of variables are given by the following vectors:

$$X_{1,i} = (\text{age}_i, \text{junior}_i, \text{fulltime}_i)$$

$$X_{2,i} = (\text{Lab.perm}_i, \text{Lab.age}_i, \text{Lab.junior}_i, \text{Lab.fulltime}_i, \text{Lab.Pubperf}_i, \text{Lab.Pubimp}_i, \text{Lab.phd}_i, \text{Lab.postdocN}_i, \text{Lab.postdocF}_i, \text{Lab.nonres}_i, \text{Lab.funding}_i, \text{Lab.contractualPub}_i, \text{Lab.contractualPriv}_i)$$

[7] Cook–Weisberg heteroskedasticity tests were performed: the null hypothesis of constant variances has been accepted for the two linear regressions (on *Pub.perf* and *Pub.imp*).

Table 1
Descriptive statistics on variables

Variable	Mean	SD	Min	Max
Pub.perf	3.61	4.75	0	42.15
Pub.imp	11.03	24.39	0	432.72
Age	44.87	9.10	26	74
Fulltime	0.50	–	0	1
Junior	0.56	–	0	1
Lab.perm	36.45	26.43	2	79
Lab.Pubperf	3.19	1.83	0	9.33
Lab.Pubimp	9.88	11.26	0	50.97
Lab.phd	0.84	0.47	0.12	3
Lab.postdocsN	0.11	0.19	0	1
Lab.postdocsF	0.40	0.63	0	5.12
Lab.nonres	0.80	0.84	0	6.35
Lab.funding	59.17	41.33	5.42	189.37
Lab.contractualPub	441.51	425.70	0	5265.64
Lab.contractualPriv	398.00	599.40	0	2267.65
Lab.age	51.79	3.48	41.62	66
Lab.fulltime	19.33	19.63	0	62
Lab.juniors	0.58	0.14	0	1
Discipline.1	0.06			
Discipline.2	0.12	–	0	1
Discipline.3	0.15	–	0	1
Discipline.4	0.07	–	0	1
Discipline.5	0.07	–	0	1
Discipline.6	0.36	–	0	1
Discipline.7	0.09	–	0	1
Discipline.8	0.08	–	0	1

A closer look of the data informs that a non-negligible share of – but not so high a subset of – dependent variables is null: 107 for *Pub.perf* (9.4%) and 142 for *Pub.imp* (12.5%). Kernel density estimates displayed in Fig. 1 show the specificity of the threshold between publishing or not. This observation led us to perform also a left censored Tobit model of the form[8]:

$$\begin{aligned} Y_i^* &= X'_{1,i}\beta_1 + X'_{2,i}\beta_2 + \varepsilon_i, \\ Y_i &= Y_i^* \text{ if } Y_i^* > 0, \\ Y_i &= 0 \text{ if } Y_i^* = 0, \end{aligned} \tag{2}$$

where Y_i is the vector of really observed dependent variables (either *Pub.perf* or *Pub.imp*) while Y_i^* is the unobserved real research effort: Below a certain level, no publication item is recorded. Such a threshold may be due to the fact that a certain level of research effort is required to publish in the best scientific journals, the ones that are recorded in the publication databases used. Here error terms ε_i are also assumed to be Normally *iid*.

[8] OLS linear regressions have also been performed for the 1027 (1134–107) publishing researchers on *Pub.Perf* and for the 992 (1134–142) researchers publishing in revues having a non null impact factor on *Pub.imp*. The results remained the same as the ones obtained with the linear regression on the whole population set.

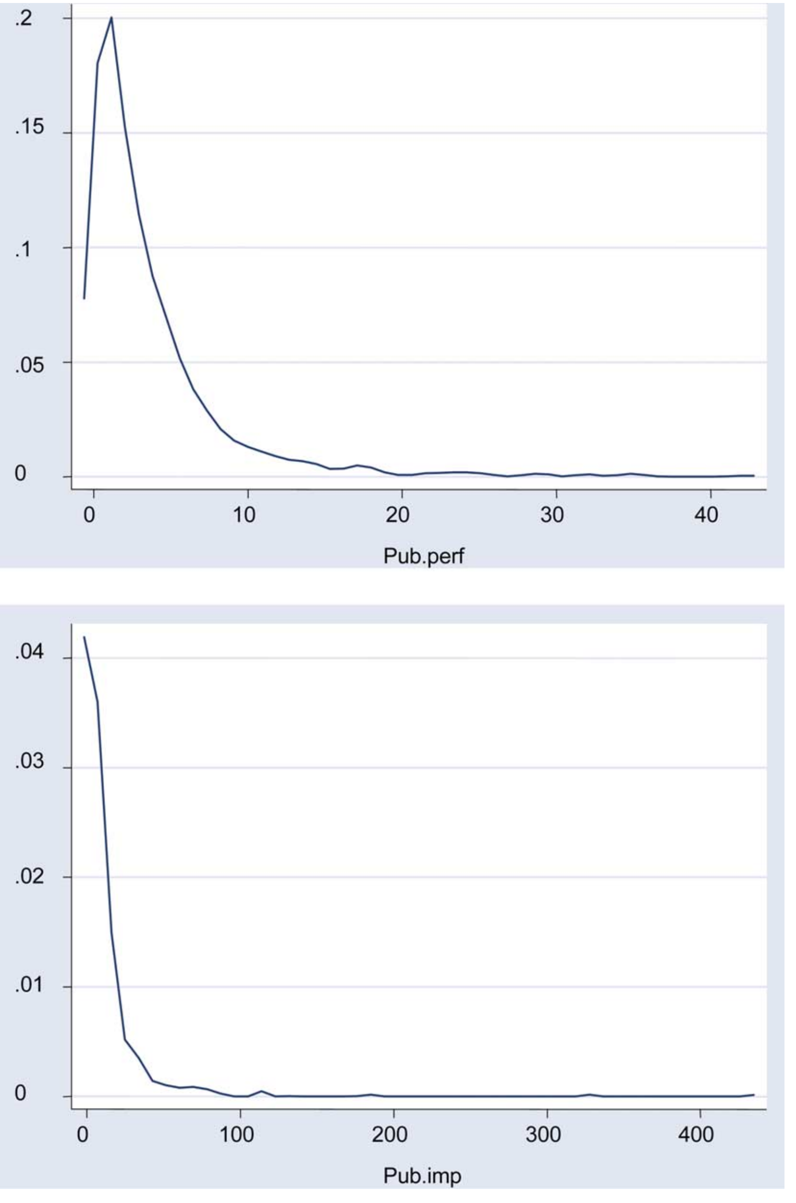

Fig. 1. Kernel density estimate graphs for *Pub.perf* and *Pub.imp*.

5. Results

The results of the four regressions are presented in Table 2 below.[9]

[9] One may first notice that the two linear regressions exhibit quite good R^2 and adjusted R^2 scores. The Pseudo R^2 computed for the Tobit regressions are much lower but their meaning is more confusing.

Table 2
Regression results

	Pub.perf		Pub.imp	
	OLS	Tobit	OLS	Tobit
Age	−0.026 (0.016)	−0.040** (0.018)	−0.138 (0.086)	−0.235** (0.096)
Fulltime	0.937*** (0.306)	1.070*** (0.326)	3.255** (1.609)	3.903** (1.749)
Junior	−3.625*** (0.295)	−4.157*** (0.319)	−12.593*** (1.553)	−16.066*** (1.722)
Lab.Pubperf	0.367** (0.156)	0.481*** (0.167)	−0.846 (0.824)	−0.3058 (0.900)
Lab.Pubimp	−0.056 (0.035)	−0.078** (0.038)	0.413** (0.188)	0.3151 (0.207)
Lab.perm	−0.019** (0.008)	−0.019** (0.009)	−0.054 (0.042)	−0.052 (0.046)
Lab.age	0.048 (0.059)	0.065 (0.064)	−0.115 (0.311)	0.138 (0.346)
Lab.fulltime	1.954** (0.864)	2.354** (0.919)	7.893* (4.543)	11.344** (4.937)
Lab.juniors	1.277 (1.087)	1.363 (1.164)	7.525 (5.714)	8.221 (6.258)
Lab.phd	0.405 (0.403)	0.234 (0.433)	0.849 (2.119)	−0.019 (2.330)
Lab.postdocsN	0.776 (0.944)	0.655 (0.998)	5.209 (4.960)	4.503 (5.348)
Lab.postdocsF	1.017** (0.429)	0.998** (0.454)	5.886*** (2.255)	5.873** (2.427)
Lab.nonres	−0.602 (0.419)	−0.537 (0.445)	−0.322 (2.201)	−0.292 (2.389)
Lab.funding	−0.003 (0.009)	−0.003 (0.010)	−0.008 (0.049)	−0.011 (0.053)
Lab.contractualPub	0.001*** (0.000)	0.001*** (0.000)	0.003 (0.002)	0.003 (0.003)
Lab.contractualPriv	0.000 (0.000)	0.000 (0.000)	0.002 (0.002)	0.004* (0.002)
Discipline.2	−0.628 (0.866)	−0.502 (0.930)	−2.019 (4.553)	−1.073 (4.999)
Discipline.3	−0.769 (0.799)	−0.462 (0.858)	−2.754 (4.201)	−0.904 (4.611)
Discipline.4	−2.449*** (0.874)	−2.669*** (0.950)	−7.029 (4.595)	−7.107 (5.100)
Discipline.5	−2.549*** (0.825)	−2.323*** (0.885)	−7.648 (4.335)	−7.363 (4.779)
Discipline.6	−1.538* (0.799)	−1.144 (0.858)	−2.777 (4.198)	−0.400 (4.608)
Discipline.7	1.553* (0.896)	2.112*** (0.957)	6.061 (4.707)	9.208* (5.142)
Discipline.8	−2.835*** (0.882)	−4.621*** (0.987)	−6.807 (4.634)	−22.899*** (5.561)
Constant	2.465 (3.454)	1.578 (3.709)	18.830 (18.146)	5.212 (19.991)
Sigma		4.343 (0.101)		23.115 (0.544)
R^2	0.2761		0.2722	
Adjusted R^2	0.2598		0.2559	
Pseudo R^2		0.0679		0.0462

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 Discipline variable, coefficient should be understood as compared with the first modality which is taken into reference.

We first find that the individual variables, which refer to the position occupied, are highly significant. The full-time and promotion dummies are both highly significant and influence positively[10] publication either corrected for impact or not. Moreover, we observe that the coefficients are much higher when publication corrected for impact is the dependent variable.

Second, we find that the age is not significant in the OLS model, but becomes significant in the Tobit regression for the intensity and the quality of publications: The effect is negative. We experienced unreported regressions in order to evidence whether these results were robust. Both the literature and the a first glance to the data (see Fig. 2) tend to suggest a productivity peak through age. Thus, we tried regression configurations with age squared, square root of age or even dummies for age categories in order to test for such a peak. Age variables remained non significant in the first model and no more can be

[10] The coefficients for *Junior* are negative: it should be recall that *Junior* stands for "not yet promoted".

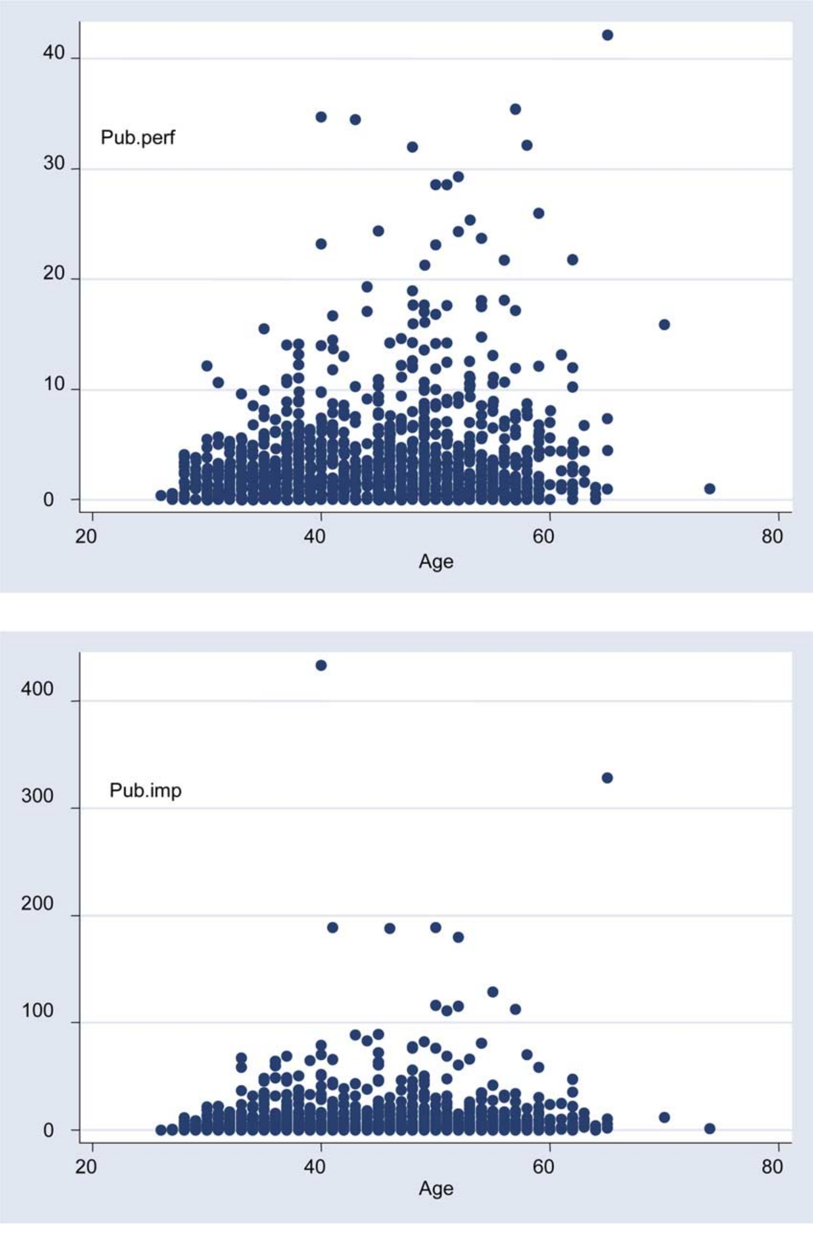

Fig. 2. Plots of agents according to their Age and to their publication performances according to *Pub.perf* and *Pub.imp*.

added in the Tobit regression. Second we tested for potential specific effect of the age in disciplines (age × discipline), but the results remained the same.

We now turn toward the collective determinants of individual productivity. Our single size related variable, i.e., the number of permanent researchers plays significantly and negatively on publication intensity: Permanent researchers publish more when they are in smaller labs. However, size measured as such is not significantly related to publication corrected for impact in both models.

The results also show that the average publication activity of colleagues plays positively on individual scores in both models. Colleagues' publications corrected for impact influence positively individual scores corrected for impact in the OLS model. We also find, curiously, that the quality of colleagues' publications affects negatively the individual performance in the Tobit model.[11] We have no convincing explanation for this last result.

Among the characteristics of colleagues we find that only the share of full-time researchers is significant and positive on individual publications, corrected or not for impact in both models (weakly on *Pub.imp* in OLS). Neither the age of colleagues, nor their promotion influence individual productivity. Thus, it seems that it is better for one's own productivity to have fulltime researchers in the immediate institutional neighborhood than older and promoted colleagues.

Turning toward the impact of the average number of the different categories of non-permanent researchers on individual productivity, we find that neither the national post-docs, nor the PhD students are significant. Only foreign post-docs influence positively all the publication productivity measures in both models, but significance is higher when publication is corrected for impact in the OLS model. The average number of non-researchers per permanent researcher is not significant.

Concerning the funding variables we find that the standard recurrent funding of the labs and the private contractual funding are not significant. The only significant and positive funding variable is the contractual public funding. Nevertheless the coefficient is rather small.

6. Discussion

In the paper, we have tested for the individual and the collective determinants of publication score of more than a thousand permanent researchers at a large European university. These first results provide some answers in the research avenue which consists in better understanding academic research organization.

The significant individual variables are the ones related to the position occupied: Full-time researchers publish more. This result confirms the ones obtained in the literature. We also found that promoted researchers publish significantly more. Thus the status and the selection effects appear to overcome the dis-incentive effect of promotion.

Usually, the literature highlights a peak in the relationship between age and productivity. We found a significant negative relation in the Tobit regressions (a productivity peak would have implied a positive coefficient for age and a negative one for age square). Nevertheless age is never significant in the standard linear regressions. This difference is due to the fact that the Tobit model offers a dedicated treatment of the non-publishing behavior in the set of journals considered. The non-significance of age in our OLS models could also be explained as follows: We take into account (usually

[11] We also wondered whether co-linearity between *Lab.Pubperf* and *Lab.pubimp* may have produced artificial results. Thus we tested the same models with either only *Lab.Pubperf* or only *Lab.pubimp* as independent variables, but the results remained identical.

unobserved) position related variables that may weaken the effects of age as suggested by Knorr et al. (1979). These variables (promotion and full-time research) seem to capture some of the previously unobserved individual effects, which may lead to the divergent publication trajectories one observes over the life cycle. Nevertheless, the effects of age on productivity remain an open question and probably need much more work to be properly understood.

Among the collective variables, we find that laboratory size affects negatively the publication performance not corrected for impact in both models: Individual researchers publish more in small labs. In our previous papers (Carayol and Matt, 2003a,b) we underlined that the most productive labs are the smallest (cf. also Bonaccorsi and Daraio, 2003). This first set of results seems to indicate that the size of the lab plays an important role both on the individual and on the collective performance of researchers. This could be explained by standard advantages linked to smaller size: Lower coordination costs, quicker decision processes, lower administrative burden, etc. Of course these explanations need deeper analysis to be confirmed. Nevertheless, if these preliminary findings could be generalized by similar studies, they would have strong policy implications in terms of research organization. Further analysis on this topic is definitely needed.

The publication scores of colleagues also matter. The intensity of publication of colleagues influences positively the researchers own production. Similarly the quality of publications of colleagues induces individual scientists to publish in journals with high impact factors. These findings are consistent with Mairesse and Turner (2002). The promotion and ages of colleagues are not significant but the share of full-time researchers is. Thus having either old or promoted colleagues does not enhance one's own publication production while having full-time researchers as colleagues stimulates one's own productivity. However, this does not mean that active university professors do not have their *raison d'être* in the research process, on the contrary. The types of position and the publication behaviors of colleagues seem to matter for individual publication. This result gives some indication about the characteristics of a favorable environment, but it does not provide any information about the interactivity between the members of the labs and its impact on individual productivity. This question of interaction is important to understand the collective dimension of science. It is also linked to the previous question related to size: Is it easier to communicate in a smaller team than in a bigger one?

Among the often-ignored role of non-permanent researchers we found that foreign post-docs enhance publication scores significantly. Nevertheless the way of the causality is not clear since most productive scholars may also be highly attractive in the eyes of potential post-docs. Moreover, post-docs are the only ones that obviously go with higher individual publication scores: Neither the PhDs nor the national post-docs are significant.

Public contractual funding (per permanent researcher) is the only significant funding variable: It plays positively on the publication intensity (not weighted for impact). One should nevertheless not conclude too fast that more standard public funding has no significant impact on productivity, and that one should privilege such a form of funding, thus supporting a shift toward a 'US-style' of academic research public funding in which funds are mostly attributed on a competitive basis. Indeed, on the one hand the intensity of recurrent public funding may depend on very specific needs and on the other hand the coefficient for public funding is rather small, meaning that if such funding is significant, its impact is rather low.

Acknowledgements

This work is part of a larger project on knowledge production at ULP. We are grateful to all members of the team and especially to its initiator Patrick Llerena. Acknowledgements extend to the administrative departments and the Technology Transfer Office at ULP, and to the CNRS Industrial Liaison Office.

References

Adams, J., Griliches, Z., 1996. Measuring science: an exploration. Proceedings of the National Academy of Science 93, 12664–12670.

Adams, J., Griliches, Z., 1998. Research productivity in a system of universities. Annales d'Economie et de Statistique 49/50, 127–162.

Arora, A., David, P.A., Gambardella, A., 1998. Reputation and competence in publicly funded science: estimating the effects on research group productivity. Annales d'Economie et de Statistique 49/50, 163–198.

Allison, P.D., Long, J.S., 1990. Departmental effects on scientific productivity. American Sociological Review 55, 469–478.

Bayer, A.E., Dutton, J.E., 1977. Career age and research professional activities of academic scientists. Journal of Higher education 48, 259–282.

Bonaccorsi, A., Daraio, C., 2002. The organization of science. Size, agglomeration and age effects in scientific productivity. In: Proceedings of the conference "rethinking science policy: analytical frameworks for evidence-based policy". SPRU, Brighton, March 21–23.

Bonaccorsi, A., Daraio, C., 2003. Age effects in scientific productivity. The case of the Italian National Research Council (CNR). Scientometrics 58, 35–48.

Boumahdi, R., Carayol, N., Llerena, P., 2003. The private contractual funding of academic laboratories: a panel data analysis, Mimeo BETA-University Louis Pasteur.

Carayol, N., 2003. Objectives, agreements and matching in science industry collaborations: reassembling the pieces of the puzzle. Research Policy 32, 887–1148.

Carayol, N., Matt, M., 2003. Does research organization influence academic production? Laboratory level evidence from a large European University, Mimeo BETA-University Louis Pasteur.

Carayol, N., Matt, M., 2003. The exploitation of complementarities in the scientific production process at the laboratory level, Mimeo BETA-University Louis Pasteur.

Cesaroni, F., Gambardella, A., 2003. Research productivity and the allocation of resources in publicly funded research programmes. In: Geuna, A., Salter, A., Steinmueller, W.E. (Eds.), Science and Innovation: Rethinking the Rationales for Funding and Governance. Edward Elgar, Cheltenham.

Cohen, W.M., Nelson, R.R., Walsh, J., 2002. Links and impacts: the influence of public research on industrial R&D. Management Science 48, 1–23.

Cole, S., 1979. Age and scientific performance. American Journal of Sociology 84, 958–977.

Cole, S., 1970. Professional standing and the reception of scientific discoveries. American Journal of Sociology 76, 286–306.

Cole, S., Cole, J., 1973. Social Stratification in Science. University of Chicago Press, Chicago.

Crow, M., Bozeman, B., 1987. R&D laboratory classification and public policy: the effects of environmental context on laboratory behavior. Research Policy 16, 229–258.

Dasgupta, P., David, P.A., 1994. Toward a new economics of science. Research Policy 23, 487–521.

Diamond, A.M., 1984. An economic-model of the life-cycle research productivity of scientists. Scientometrics 6 (3), 189–196.

Diamond, A.M., 1986. The life-cycle research productivity of mathematicians and scientists. The Journal of Gerontology 41, 520–525.

Ellison, G., 2002. The slowdown of the economics publishing process. Journal of Political Economy 110, 947–994.

Fontana, R., Geuna, A., Matt, M., 2004. Firm size and openness: the driving forces of university-industry collaboration, In: Caloghirou, Y. Constantelou N., Vonortas, N. (Eds.), Knowledge Flows in European Industry: Mechanisms and Policy Implications (London, Routledge, Forthcoming).

Fox, M.F., 1992. Research, teaching and publication productivity: mutuality versus competition in academia. Sociology of Education 65, 293–305.

Frey, B.S., 2003. Publishing as prostitution? Choosing between One's Own Ideas and Academic Success. Public Choice 116, 205–223.

Hansen, W.L., Weisbrod, B.A., Strauss, R.P., 1978. Modelling the earnings and research productivity of academic economists. Journal of Political Economy 86, 729–741.

Knorr, K.D., Mittermeier, R., Aichholzer, G., Waller, G., 1979. Individual publication productivity as a social position effect in academic and industrial research units. In: Andrews, F. (Ed.), The Effectiveness of Research Groups in Six Countries. Cambridge University Press, Cambridge, pp. 55–94.

Laband, D.N., Tollison, R., 2003. Dry holes in economic research. Kyklos 53, 161–173.

Lehman, H.C., 1953. Age and Achievement. Princeton University Press, Princeton.

Lehman, H.C., 1958. The chemist most creative years. Science 127, 1213–1222.

Lehman, H.C., 1960. The decrement in scientific productivity. American Psychologist 15, 128–134.

Levin, S.G., Stephan, P.E., 1991. Research productivity over the life cycle: evidence for academic scientists. American Economic Review 81, 114–132.

Long, J.S., 1978. Productivity and academic position in the scientific career. American Sociological Review 43, 880–908.

Long, J.S., McGinnis, R., 1981. Organizational context and scientific productivity. American Sociological Review 46, 422–442.

Mairesse, J., Turner, L., 2002. A Look at individual differences in scientific research productivity: an econometric analysis of the publications of the French CNRS physicists in condensed matter (1980–1997), In: Article presented at the Conference 'Rethinking Science Policy: Analytical Frameworks for Evidence-Based Policy', SPRU, Brighton, March 21–23.

McDowell, J.M., 1982. Obsolescence of knowledge and career publication profiles: some evidence of differences among fields in costs of interrupted careers. American Economic Review 72, 752–768.

Meyer-Krahmer, F., Schmoch, U., 1998. Science-based technologies: university–industry interactions in four fields. Research Policy 27, 835–852.

Mohnen, P., Hoareau, C., 2002. What type of enterprise forges close links with universities and government labs? Evidence from CIS 2. Managerial and Decision Economics 24, 133–145.

Pelz, D.C., Andrews, F.M., 1976. Scientists in Organizations: Productive Climates for Research and Development. Institute for Social Research, Ann Arbor, MI.

Poyago-Theotoky, J., Beath, J., Siegel, D.S., 2002. Universities and fundamental research: reflections on the growth of university–industry partnerships. Oxford Review of Economic Policy 18, 10–21.

Riyanto, Y.E., Yetkiner, I.H., 2002. A market mechanism for scientific communication: a proposal. Kyklos 55, 563–568.

Salter, A.J., Martin, B.R., 2001. The economic benefits of publicly funded basic research: a critical review. Research Policy 30, 509–532.

Stephan, P.E., 2001. Educational implications of university–industry technology transfer. Journal of Technology Transfer 26, 199–205.

Stephan, P.E., 1998. Gender differences in the rewards to publishing in academe: science in the 70's. SEX Roles 38, 11–12.

Stephan, P.E., 1996. The economics of science. Journal of Economic Literature 34, 1199–1235.

Stigler, G.J., Friedland, C., 1975. The citation practices of doctorates in economics. Journal of Political Economy 83, 477–507.

Waldman, M., 1990. Up-or-out contracts: a signaling perspective. Journal of Labor Economics 8, 230–250.

Weiss, Y., Lillard, L.A., 1982. Output variability, academic labor contracts, and waiting times for promotion. Research in Labor Economics 5, 157–188.

Zuckerman, H.A., Merton, R.K., 1972. Age, aging, and age structure in science. In: Riley, M.R., Johnson, M., Foner, A. (Eds.), A Sociology of Age Stratification: Aging and Society, vol. 3, Russel Sage foundation, New York, Reprinted in: Storer, N.W. (Ed.), 1973. The Sociology of Science: Collected Papers of R.K. Merton, Chicago University, Chicago Press, pp. 497–559.