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ScienceDirect
Research Policy 36 (2007) 1107–1127
research policy
www.elsevier.com/locate/respol

Inventors and invention processes in Europe: Results from the PatVal-EU survey

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Received 13 February 2006; received in revised form 28 February 2007; accepted 4 July 2007
Available online 11 September 2007

Abstract

Based on a survey of the inventors of 9017 European patented inventions, this paper provides new information about the characteristics of European inventors, the sources of their knowledge, the importance of formal and informal collaborations, the motivations to invent, and the actual use and economic value of the patents.

Keywords: Patent; Inventor; Collaboration; Licensing; Invention process

1. Introduction

This paper provides new information, not available from other sources, on the characteristics of the invention processes in Europe, and on the economic use and value of European patents. Our data are drawn from a survey (PatVal-EU, or PatVal for short) of 9017 patents granted by the European Patent Office (EPO) between 1993 and 1997, located in France, Germany, Italy, the

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0048-7333/$ – see front matter
doi:10.1016/j.respol.2007.07.008

Netherlands, Spain and the United Kingdom (hereafter "EU6").

There is a rich literature on the measurement of innovation (for surveys see Griliches, 1990; Patel and Pavitt, 1995). Along with input data such as R&D expenditures and the human capital employed in research, patents have become the most common measure of innovation output (see Hall et al., 2001, for a survey). A convenient feature of patents is that they resemble invention counts.[3] Moreover, they have been well documented, especially in recent years thanks to the extensive on-line information that can be conveniently organized into databases. Another advantage of patents is that they can combine different indicators. For example, patent citations have been used to measure their importance and economic value (Trajtenberg, 1990; Hall et al., 2005; Harhoff et al., 1999), or to describe the direction and geographical extent of knowledge flows among inventors and patent holders (Jaffe et al., 1993; Verspagen, 1997). Similarly, patent claims have been used to account for the scope of patent protection (Lerner, 1994).

However, patents also have shortcomings. They relate only to certain types of inventions, and there are vast differences across firms, industries and countries in the precision with which patents measure innovation output. Moreover, there is still ambiguity about what exactly patent indicators measure. For example, some studies have shown that patent citations are a noisy measure of information flows (Almeida and Kogut, 1999; Singh, 2005), particularly because many citations are added not by applicants, but by the patent examiners or just to avoid infringements (e.g. Harhoff et al., 2006; Alcacer and Gittleman, 2006). Also, Lanjouw and Schankerman (2004) show that it is hard to distinguish whether patent claims are a measure of patent scope, degree of protection or of value. Similarly, citations are correlated with several aspects of the patent, e.g. its legal robustness and not just with its value.

The patent data and indicators presently employed in the literature are drawn largely from patent documents. As a result, information not in the patent files is mostly unavailable. This implies that while certain aspects about patents or underlying invention processes have been studied extensively, we have little or practically no information for others. For example, we do not know much about the inventors, or the nature of the research or other processes that gave rise to the invention; we typically have no measures of the value of the patent other than the proxies that we can retrieve from the patent document; and we know very little about whether the patent is used or not, whether it is licensed, or whether it is further developed into a new product by the applicant.

The most natural way of collecting this information is through surveys. Griliches (1990) himself noted that patent surveys had not been undertaken for a long time. Since then, Scherer, Harhoff and Vopel conducted a patent survey in the US and Germany to explore the distribution of the economic value of patents (Scherer and Harhoff, 2000; Harhoff et al., 2003b). The Yale survey (Levin et al., 1987) and the CMU survey (Cohen et al., 2000) investigated the motivations for patenting of US firms. Cohen et al. (2002) presented survey evidence on the role of patents for diffusing information in Japan relative to the US. Arundel and Steinmueller (1998) used the Community Innovation Survey to look at patents as information channels in Europe. Meyer (2000) interviewed a group of European inventors of nanotechnology patents to understand the connection between their invention and the scientific research that they cite. Tijssen (2002) performed a mail survey amongst Dutch inventors to understand the contribution of science to successful technical inventions, and to test the validity of patent citations to scientific literature as indicators of science dependency. While these surveys provide new data, they have limited European coverage and are mostly biased towards large companies.

In order to overcome some of the weaknesses implicit in earlier studies, PatVal is a large-scale survey designed to be representative of the universe of patents in our EU6 countries. It covers all technological fields, deals with both for-profit and non-profit applicants, and collects information on small, medium and large business companies. In 2003, patents with the first inventor located in one of our EU6 represented 42.2% of all EPO patents, and 88% of the EPO patents whose first inventor was in one of the EU-15 countries. PatVal's main objective is to collect information about patents and the underlying invention process on issues that had not previously been explored in depth because of lack of information in the patent documents. It also provides new proxies for variables like knowledge flows or patent value for which the present measures are subject to the discussions noted earlier.

This paper is the first of a series of contributions based on the PatVal survey that explore these issues. It focuses

[3] It is worth to recall the difference between the concepts of invention and innovation. We refer to inventions as novel ideas, processes, methods, objects that result from R&D activities. Inventions may (or may not) be patented. Inventions become innovations when they are transformed into commercialisable products or technologies, by means of investments in complementary manufacturing, technological and marketing assets. As a market of fact, not all inventions turn into innovations and reach the market.

Table 1
The PatVal-EU survey: targeted number of patents and response rates

	GER	SP	FR[a]	IT	NL	UK	EU6
Number of patents whose inventors were contacted	10,215	815	4,199	1,857	2,594	7,846	27,531
Number of patents whose inventors responded	3,346	269	1,486	1,250	1,124	1,542	9,017
Response rate (responses/contacts) (%)	32.8	33.0	35.4	67.3	43.3	19.7	32.8
Country share of patents in the final sample (%)	37.1	3.0	16.5	13.9	12.5	17.1	100

Distribution by country.
[a] The French survey was directed to both inventors and applicant organisations.

on three areas: inventors; research collaborations and spillovers; use and economic value of the patents. In all of these areas, either the literature does not provide information on some relevant topic, or there is ambiguity in the existing measures, or the existing information is potentially incomplete. The three central sections of this paper discuss the PatVal data that fill some of these gaps. They all start with a brief discussion of the existing literature.

Section 2 describes the survey and the data collected through the PatVal questionnaire. Sections 3–5 are the central sections on the three topics above. The final section concludes and summarizes the results. Appendix 1 describes the methodology employed to carry out the PatVal survey. Appendix 2 provides our definition of the uses of patents. Appendix 3 describes our test for assessing the inventors' bias in their answers about the patent value.

2. The PatVal-EU survey

The full-scale PatVal survey started in May 2003, and ended in January 2004. The questionnaire was submitted to the inventors of 27,531 patents granted by the EPO with a priority date of 1993–1997, and located in France, Germany, Italy, the Netherlands, Spain and the United Kingdom. Appendix 1 describes the details of the questionnaire, the sampling strategy, the pilot tests, the problems faced during the survey, and the solutions that we adopted.[4]

Our European inventors returned 9216 questionnaires covering 9017 patents.[5] Table 1 shows the number of "contacted patents" (i.e., patents whose inventors received the questionnaire) and the final composition of the PatVal sample by country: 3346 patents from Germany, 1486 from France, 1542 from the UK, 1250 from Italy, 1124 from the Netherlands, and 269 from Spain.

There are two issues that we want to highlight at the outset of our discussion. First, because the distribution of the economic value of patents is very skewed, we increased the number of valuable patents in our sample by over-sampling patents that were either opposed under the EU opposition procedure before a patent is granted, or that were not opposed, but had received at least one citation by the time we sent out the questionnaires (May, 2003). As we shall note in Section 5.3, both oppositions and citations are correlated with the value of the patents. Our final 9017 patents include 43.2% patents that were either opposed or cited while the population of EU6 patents with a priority date of 1993–1997 only has a share of 28.5% of patents of this type. With respect to the population, our sample will therefore over-represent patent characteristics that are positively correlated with opposition or citation. This problem did not turn out to be important when employing sampling weights that correct for the stratified sampling.[6] Therefore, we report all of our results in this paper without correcting for over-sampling.

A second issue arises because the respondents in our survey – inventors – may not be the best-informed indi-

[4] While the original target was to focus on the period 1993–1997, some patents with a priority date of 1998 crept into the sample. However, they are very few and we continue to consider the PatVal window as 1993–1997.

[5] The number of questionnaires is larger than the number of surveyed patents because we obtained responses from more than one inventor for 192 patents. Since the statistics in the paper are based on the number of patents, we randomly picked one questionnaire for each multiple-response patent. However, the multiple responses were used to check for the consistency of the information provided by different inventors. Clearly, not all the questionnaires answered all the questions. Hence, there are generally some missing data for our variables.

[6] Using the computed sampling weights and correcting for non-response, we found that the corrected results do not differ substantially from the results presented in the tables and figures presented in this paper. Differences mainly concern a small share of patents at the very right-hand tail of the patent value distribution. Intuitively, this is due to the fact that even in the 28.5% of opposed or cited patents, there are only very few cases that several standard deviations above or below the mean of the respective variable. As a result, by over-sampling opposed or cited patents we increase the share of these patents just by percentage points. Appendix 1 explains in greater detail our sampling procedures. The corrected tables and figures are available upon request.

Table 2
Composition of the sample by "macro"-technological classes and by type of inventors' employers

	Large firms (%)	Medium sized firms (%)	Small firms (%)	Private Research Inst. (%)	Public Research Inst. (%)	University (%)	Other Govt Inst. (%)	Others (%)	Total (%)
Electrical Engineering (15.8%)	79.9	5.5	9.1	0.4	1.8	2.9	0.1	0.3	100
Instruments (10.9%)	60.4	7.9	16.7	3.2	3.8	7.0	0.1	0.9	100
Chemicals and Pharm (18.5%)	81.1	4.9	4.9	0.6	2.6	5.7	0.1	0.1	100
Process Engineering (24.9%)	64.4	12.3	17.2	0.7	2.2	2.4	0.2	0.6	100
Mechanical Engineering (29.8%)	67.8	10.5	17.8	0.2	1.1	1.2	0.2	1.2	100
Total (100%)	70.6	8.8	13.7	0.8	2.0	3.2	0.2	0.7	100

Number of observations = 8809. The share of patents by technological class (first column) use 9014 observations.

viduals with respect to *all* of our questions. Inventors are likely to have excellent information on their own biography and the invention process. For some PatVal questions, however, company managers might have been better informed—e.g., for questions on the value of the patents or their economic use. However, given the large scale of our survey, it would have been virtually impossible to find the best contact for each of the many applicant organisations in our sample to provide information about a given patent.[7] The inventor's address is in the patent document and, in addition, the inventor is a well-defined "type". A generic person "knowledgeable" about the patent is a more blurred type. He could be a manager in the R&D, legal or other department, or the boss of the inventor, or the technology-licensing manager in a university. Moreover, since we conducted the survey in 2003, our knowledgeable individual for a patent applied for in 1993–1997 might have no longer been employed in the organisation. If we sent the questionnaire to the organisation without checking who was going to answer, it would be unlikely to produce better estimates and response rates than asking the inventors. We concluded that the latter was the best option, at the scale of our survey, for systematically finding somebody who had a reasonably good knowledge about the specific patent in question.

Furthermore, we also checked whether the inventors were knowledgeable enough to respond. Especially during the pilot tests (see Appendix 1), and particularly for the questions on the value of the patents and their use, we asked them explicitly whether they were sufficiently informed about the topic. In general, they had a pretty good idea of the answer. As discussed in Appendix 3, on the specific question of the patent value we even produced a statistical test on 354 French patents for which we had an answer from both an inventor and a manager. We found that the inventors tended to over-estimate the value of their patents, but the bias is small.

As a first snapshot of the PatVal sample, Table 2 describes the composition of the dataset by macro-technological classes and by affiliation of the inventors. The PatVal patents are classified into five "macro"-technological classes: Electrical engineering, Instruments, Chemicals and Pharmaceuticals, Process engineering, and Mechanical engineering.[8] The survey also provides information about inventors' employers: small firms (less than 100 employees), medium firms (100–250 employees), large firms (more than 250 employees), universities, public or private research institutions, and others.[9]

The percentage shares of the technological classes in Table 2 (left-hand column) show that Mechanical Engineering and Process Engineering are the most represented technologies in the EU6. As expected, the

[7] As we shall discuss in Appendix 3, we could do this only for the French questionnaire.

[8] We used the ISI-INPI-OST classification system elaborated by the German Fraunhofer Institute of Systems and Innovation Research (ISI), the French Patent Office (INPI) and the Observatoire des Sciences and des Techniques (OST). This classification distinguishes between 30 "micro" technological classes and 5 "macro" technology areas based on the International Patent Classification (IPC). For the concordance between ISI-INPI-OST technological classes and EPO IPC classes, see Hinze et al. (1997). For the PatVal statistics across the 30 "micro" technological classes, see the PatVal Final Report (PatVal-EU, 2005).

[9] We adopted the European Commission's convention that small-medium firms have fewer than 250 employees.

business sector and in particular, large companies, are the most common source of inventions. The business sector accounts for about 93% of all PatVal patents. Universities account for 3.2%, and other Public Research Institutions for 2%. Moreover, the importance of the large versus small and medium firms differs across the EU6. The highest share of inventors employed in large companies is in Germany (79.9%), followed by France, Italy, the UK (all around 60–65%) and Spain (54%).

3. Who are the European inventors?

Who are the European inventors? What is their educational background? What are their motivations to invent?

The economic and sociological literature has studied the determinants of researchers' productivity. It has typically focused on scientists, showing that their productivity distribution is skewed (Lotka, 1926; Allison and Stewart, 1974; Cole, 1979; Merton, 1968; Arora et al., 1998). Moreover, age and vintage matter. Scientists become less productive as they get older, although there are differences across research fields and over time (Levin and Stephan, 1991; Jones, 2005). This is borne out after controlling for other observable characteristics of the individual. However, a lack of information on industrial inventors, particularly on their individual characteristics, has held back the study of their productivity. There is practically no large-sample empirical work on the matter. The few existing studies employ small samples. For example, Narin and Breitzman (1995) tested Lotka's inverse square law of productivity in a sample of inventors in the R&D departments of four companies in the semiconductor industry. Similarly, Ernst et al. (2000) analysed the distribution of patents' quantity and quality across inventors working in 43 German companies in the chemical, electrical and mechanical engineering industries. Their results suggest that inventors' technological performance is highly concentrated, with few key inventors responsible for a large part of the firm's technological output. By using data on publication and patent records at the level of the individual researcher, Meyer (2006) studied the relationship between scientific and technological performance in nano-science and nano-technology in the UK, Germany and Belgium.

The PatVal survey provides a unique opportunity to explore the characteristics of individual inventors, such as their sex, age, education, motivations to invent, and job mobility. Table 3 shows that the share of female inventors is remarkably low. Only 2.8% of the inventors in our PatVal sample are women. In Chemicals and Pharmaceuticals this share reaches 7.4%, while it drops to 1.1% in Mechanical Engineering. There is some variation across countries as well. Spain employs 8.2% female inventors, while Germany is the other extreme with only 1.6%. These shares are even lower than the already small share of women among higher education researchers in the EU-15. According to the European Science & Technology Indicator Report (European Commission, 2003), this share is 29% for all disciplines, 23% for science, and 12% for engineering. There is no reason to believe that PatVal systematically under-sampled women, as we carefully selected patents in ways that produced no bias that we could not control for. Moreover, even in the EU-15, the lowest share of women is in engineering, and patenting is frequently an engineering activity. Also, in PatVal the participation of women is higher in Chemicals and Pharmaceuticals, which is more science-oriented, and it is lowest in Mechanical Engineering, a typical engineering field.

According to Commission data, female participation in science and engineering declines along the career path. Data on this phenomenon are scarce. However, Commission data show that the gap between the percentage of men and women in academia increases dramatically as we move from undergraduates, where the shares are similar, to doctoral students, assistant professors, associate professors and full professors, where the gap is

Table 3
Sex, age and education of inventors

	% of female inventors	Average age of inventors	% of inventors with tertiary education	% of inventors with PhD degree	% of inventors who changed employer after invention
Electrical Engineering	2.0	43.3	82.3	19.1	27.04
Instruments	2.7	44.6	82.0	33.4	25.42
Chemicals and Pharm	7.4	44.5	91.8	59.1	19.99
Process Engineering	2.1	46.6	72.7	22.4	21.20
Mechanical Engineering	1.1	46.2	66.3	9.3	21.54
Total	2.8	45.4	76.9	26.0	22.47

Distribution by technological class. Number of observations differs across columns, between 8861 (age) and 8963 (gender).

huge. A similar effect might occur in patenting. Table 3 also reports that the average age of our inventors is 45, which suggests that the production of a patent occurs when people are no longer young researchers, at least in Europe. Only 5% of the inventors in our sample are younger than 30. More than 60% are between 30 and 50-years-old. About 30% are between 50 and 60, and only 5% are older than 60. Moreover, we find that there is little variation across technological classes and countries. If invention is a process that occurs when people have completed the initial stages of their careers, then women are increasingly left out, consistent with observed academic data in which they are gradually more and more under-represented in senior positions along the career path.

To summarize, the low share of women inventors seems to be consistent with two other observations: the relatively low participation of women in engineering, and the reduced share of women along the career path. However, this does not tell us why women are less active in engineering than science, or about why they lose ground along their career path. We thus contribute to the growing literature on the gender gap in science and technology by exploring the gender gap for patent inventors. Our data also confirm that women provide a considerably unexploited potential of human capital in Europe. In addition, the PatVal data raise the question of why European inventors are relatively old. Unfortunately, there are no systematic data on the average age of scientists and researchers in Europe, even though existing evidence suggests that they are relatively old, too (European Commission, 2003). Our data are consistent with this view. Moreover, the lack of variation across countries and technologies reinforces the perception that the reasons are institutional rather than technical or any other. Again, this suggests directions for further research on this matter.

Table 3 also reports the share of inventors with tertiary education. Most European inventors (76.9%) have a university degree, but the share of inventors with a doctorate is only 26.0%. The shares of inventors with a university degree or a PhD vary among technological classes. The best-educated inventors are in Chemicals and Pharmaceuticals: 91.8% of them have a university degree, and 59.1% have a PhD. The least educated ones are in Mechanical Engineering: 66.3% have a university degree and 9.3% hold a PhD. The differences across countries (not shown in table) are even more pronounced. Germany has the largest shares of both tertiary-educated inventors (85.3%) and PhDs (35.2%). Spain, France, the Netherlands, and the UK are close to the EU6 share while Italy lags behind. Its share of inventors with tertiary education is only 56.7%, and PhDs account for only 3.1% of all Italian inventors.[10] By employing multiple correlation analysis on a sub-sample of 793 PatVal-EU inventors, Mariani and Romanelli (2007) found that the inventors' level of education, together with the employment in a large firm and the involvement in large-scale research projects positively affect the number of patents that an inventor produces over his career. These factors, however, do not affect directly the expected value of the inventions. They do only indirectly, as they found that the number of inventions explains the probability of producing a technological hit.

Recent contributions have noted that there is a positive correlation between researchers' productivity and their mobility. They argue that inter-firm and intra-firm mobility serve as a mechanism for creating an accurate match of employee and employer characteristics (Liu, 1986; Topel and Ward, 1992). Trajtenberg (2005) and Trajtenberg et al. (2006) is one of the first to analyse the relationship between mobility and productivity for R&D personnel. The author uses data on 1,565,780 inventors listed on U.S. patent documents. Overall, 216,581 (33%) of the inventors are movers which means that these inventors changed their employer at least once. Trajtenberg (2005) confirms the findings of the labour economic literature that mobility has a positive impact on inventive output, in particular, patents of mobile inventors receive more citations. Using instrumental variables techniques, Hoisl (2007) shows for the German sub-sample of the PatVal-EU inventors that there exists a simultaneous relationship between inventor mobility and inventor productivity: movers are more productive than non-moving inventors. Moreover, more productive inventors are less likely to move. Moreover, the mobility of human capital produces knowledge spillovers across organisations (Klepper, 2001). In fact, the job mobility of European inventors is limited. As discussed in Appendix 1, we made a considerable effort to limit the potential undersampling of mobile inventors, who are more difficult to trace because their patent address does not match the recent telephone directories that we used to find our inventors. We cannot completely rule out that PatVal data contain a bias against mobile inventors, but we have restricted the problem.

[10] The hypothesis that cross-country differences depend on the technological specialisation of the countries is not supported by our data. The share of Italian patents in sectors like Mechanical Engineering or Electrical Engineering, which have the lowest share of PhDs, is not significantly larger than the share of German or Dutch patents in the same sectors (see the PatVal-EU Report, 2005).

Table 4
Inventors' rewards

	GER	SP	FR	IT	NL	UK	Total
Average importance of inventors' rewards							
Monetary rewards	3.0	2.1	3.6	3.0	2.7	3.0	3.1
Career advances and opportunities for new/better jobs	2.7	2.6	3.3	3.1	2.9	3.3	3.0
Prestige/reputation	3.7	3.3	2.9	3.1	3.2	3.7	3.4
Inventions increase performance of the organisation the inventor works for	4.1	4.1	4.1	4.0	4.1	3.9	4.0
Satisfaction to show that something is technically possible	4.0	4.0	3.9	3.9	3.9	4.0	3.9
Benefits in terms of working conditions as a reward by employer	3.0	2.2	1.9	2.8	2.2	2.4	2.6
Share of inventors who received monetary compensation							
%Monetary compensation	61.3	14.7	NA[a]	23.1	17.5	28.2	41.7
%Permanent	4.6	3.2	NA[a]	5.2	3.8	3.2	4.6
%Transitory	56.7	11.5	NA[a]	17.9	13.6	25.0	37.1

Number of observations differs across rows, between 7360 (monetary compensation) and 8424 (satisfaction).
[a] France not included because of too many missing data.

We discuss here the responses to the PatVal question that asked how many times the inventor-changed job after the surveyed patent. Since the survey took place in late 2003, this is a 6–10 year window. The furthermost right-hand column of Table 3 shows that most inventors never changed job during this period. The EU6 share of inventors who never moved is 77.5%, with little variation across technological classes. There are differences, however, across countries (not shown in table). The least mobile inventors come from Spain, where almost 90% never changed job, followed by Germany (83.1%) and France (82.3%). At the other extreme, 34.7% of UK inventors changed job at least once, followed by the Netherlands (30.1%). Most of the mobile inventors moved only once. The share of EU6 inventors who moved more than once is 7.7%, and the share of inventors who changed employer more than three times is 0.8%.

Finally, we investigate the motivations of inventors to invent. Table 4 reports six motivations, which we asked inventors to rate from 1 (not important) to 5 (very important). We distinguished between social and personal motivations – i.e. effects of the patented invention on employer's performance, personal satisfaction, prestige and reputation – and monetary rewards or career advances. The question focused on the patent under investigation. This is because some questions were specific to it, particularly whether the inventors obtained rewards for the patent. However, because these motivations are likely to be general, we interpreted them broadly as well.

According to the surveyed inventors, social and personal motivations are on average more important than money or career advances (Table 4). The rankings are similar across the EU6. We cannot rule out that these results reflect aspects of social desirability, but in a tentative way, they suggest that industrial inventors have similar motivations as members of the scientific community (Dasgupta and David, 1994). Our inventors might have been hesitant in declaring that they cared about selfish concerns like money or career, or they feared that their employers would learn of their answers and then remark that they were concerned about their performance. But even if our inventors were concerned about hiding their quest for money or career, or they wanted to flag their concern about their employer, they would not have given high marks to an independent question on personal satisfaction.

We think instead that PatVal uncovers another interesting direction for further research. Both scientists and industrial inventors are creative individuals, and creative individuals have common characteristics, motivations and goals. We emphasise three similarities. First, as human capital becomes more important, the owners of this asset, whether scientist or inventor, care about things that enhance the perception of the asset's value. Thus, prestige and reputation are important. In turn, this may be because of personal satisfaction like fame and glory, or for more instrumental reasons like the opportunity this creates for future monetary rewards. Second, an individual benefits from the growth of the organisation in which he works because this favours his own prestige, growth or visibility as well. This may then explain why our inventors care about the performance of their employer. Third, unlike other professions, creativity, the search for knowledge, and the ability to show that something is possible, can be personally enticing. Thus, scientists and inventors may engage in it simply for consumption purposes, which explain the importance of personal satisfaction.[11]

Finally, Table 4 shows the percentage of inventors that received monetary compensations for the patent under investigation. In Germany, a compensation scheme to reward inventors is established by law, which explains the unusually high share for this country. When German employers claim inventions developed by their employees, they have to compensate them "reasonably" on the basis of the expected value of the invention, and following the guidelines provided by the German Employees' Inventions Act passed in 1957 (Harhoff and Hoisl, 2007). In other countries, there are no official rules, and any compensation stems from the specific incentive policies of firms. After Germany (61.3%), the UK shows the highest share (28.2%). As we shall also see later in this paper, this is consistent with the UK's greater degree of technological entrepreneurship. UK inventors may receive compensation associated with profit-sharing or similar mechanisms which are more typical of smaller concerns. The lowest shares are in Italy (23.1%), the Netherlands (17.5%) and Spain (14.7%). In general, apart from Germany, and partly the UK, these figures show that employers rarely provide their inventors with monetary incentives. Table 4 also shows that, when these incentives exist, they are typically transitory.

4. Collaborations, spillovers and sources of knowledge

4.1. Sources of knowledge spillovers

A growing literature has studied the sources of knowledge that firms and scientists use for invention and innovation, and the mechanisms with which they obtain this knowledge. One is the creation of formal and informal networks of collaboration among researchers or institutions. Knowledge spillovers, which are more intense when there is geographical proximity, also imply access to external knowledge, with implied benefits (Jaffe, 1986; Jaffe et al., 1993). Empirical evidence confirms the clustering of innovative activities and the geographical dimension of knowledge spillovers. Verspagen (1997) estimates their effect on firm and regional economic growth. In addition, there are sectoral differences in spatial clustering. Skilled- and R&D-intensive industries benefit to a greater extent from co-location and knowledge spillovers (Audretsch and Feldman, 1996).

In order to assess whether firms or research institutions rely on each other's knowledge bases, and to measure the geographic dimension of this exchange, most contributions use patent citations. Jaffe et al. (1993) analysed the spillovers across geographically close inventors. Similar studies have been carried out for Europe (Verspagen, 1997; Verspagen and De Loo, 1999; Verspagen and Schoenmakers, 2004). For the US and Japan, Branstetter (2001) suggests that knowledge spillovers are primarily intra-national in scope. Although interesting, the validity of these results depends on the reliability of patent citations as a measure of knowledge flows. However, this is not widely accepted. Jaffe et al. (2000) confirm that patent citations reflect knowledge spillovers as perceived by the participants, albeit with substantial noise. Also Jaffe et al. (1998) find that two-thirds of the citations to patents of the NASA-Lewis Electro-Physics Branch could be related to spillover effects. By contrast, Alcacer and Gittleman (2006) show that an important fraction of patent citations are included by examiners rather than by inventors. This makes patent citations a noisy measure of the extent and direction of the knowledge flows. Moreover, these contributions do not explain the sources of knowledge spillovers. Only some recent studies show that they are not unintentional, and that the rise of externalities depends on the complementary actions of economic agents (Zucker et al., 1998). Harhoff et al. (2006) even argue that European patent citations should not be used at all for spillover analysis, because 93% of these citations are generated by the examiner or search officer at the European Patent Office.

The PatVal data allow us to consider the sources of spillovers and knowledge flows without resorting to citation measures. This section uses different indicators from PatVal to shed some light on these issues. It examines the importance of R&D collaborations among individuals and organisations, the role of geographical proximity to establish them, and the use of different sources of knowledge in the invention process.

4.2. The role of collaborations in the production of inventions

The patent document lists the names of the inventors. Only one-third of the PatVal patents involve a single inventor. Thus, a patented invention is typically the result of teamwork. The patent document, however, does not indicate whether the collaborations are among

[11] We also found that there are differences in the ranking of the motivations across macro technological classes. This is consistent with our discussion. Even in science, the scientific ethos is higher for instance in physics or other more traditional hard sciences.

inventors belonging to the same or different organisations, or give details of the type of collaboration they establish.

Co-application (i.e. patents applied for by more than one organisation) is the only information concerning collaboration provided by the patent document. The literature has used this information to identify R&D collaborations, and to proxy for the sharing of intellectual property rights (Hagedoorn, 2003). However, there may be collaborations that do not end up in a joint application. At the same time, the information on co-applications does not provide any details on several features of the collaboration, like which inventor belongs to which organisation, or whether they all belong to the same one, or what the type of collaboration is. Moreover, as Hagedoorn (2003) himself points out, firms consider this type of partnering sub-optimal, due to the legal complexities involved in the management of intellectual properties across firm boundaries and international patent jurisdictions. Hagedoorn also shows that co-patenting is more frequent in chemicals and pharmaceuticals where patent protection is stronger and the scope for legal controversies is more limited. Therefore, apart from under-estimating the extent to which there is collaboration in R&D, the data on co-patenting may be biased towards specific technologies.

The PatVal questionnaire asked the inventors whether some of their co-inventors belonged to other organisations. It also asked whether the patent was developed in collaboration with other partners and if the collaboration was among individuals or among institutions. These questions make it possible to uncover collaborations that are not "visible" from the patent document.

The first column of Table 5 shows that the EU6 share of co-applied patents in our sample is 3.6%. It ranges between 5.4% for France and 2.8% for the UK. It is slightly higher in the second column where we include among the co-applicants companies belonging to the same corporate group. The third column reports the share of patents in which the inventor declared that some co-inventors were from another organisation. This share is 15% for the EU6, which is substantially higher than the co-applied patents. This is a stunning result. It is also larger for the UK, and smaller for Spain and Italy. Additional analysis of our data revealed that the share of patents with external inventors is smaller for firms, and particularly for large firms (about 12%), as compared to non-profit research institutions. As expected, firms tend to internalise the invention process, and to mostly coordinate internally the production of invention and transfer of knowledge among inventors. We also found that firms, and particularly large firms, had a lower share of co-applications.

The share of patents in which the inventors declare that there were collaborations with other institutions is even higher. Along with the higher share of collaborations with external inventors, this suggests that co-applications capture a small fraction of actual collaborations. Collaborative patents in the EU6 are slightly more than 20%, with the Netherlands reaching 34.5%, and Germany falling to 13.3%. The two furthermost righthand columns of Table 5 show that about three-quarters of the collaborations are of a formal nature. In the questionnaire, we defined formal collaborations for the respondents as relationships based on well-defined contracts among the parties. Firms, and particularly large firms, exhibit a lower share of collaborative patents compared to research institutions and universities.

Table 5
Research collaborations in the invention process

	%Co-applied patents among independent organisations	%Co-applied patents[a]	%Patents with external co-inventors[a]	%Patents developed in collaboration with other partners	%Patents developed with formal collaborations	%Patents developed with informal collaborations
GER	3.1	5.0	15.4	13.3	9.5	3.8
SP	3.0	3.4	9.4	19.6	16.9	2.7
FR	5.4	7.0	12.3	22.7	19.8	2.9
IT	4.0	4.8	9.6	21.9	14.3	7.6
NL	3.3	8.2	15.9	34.5	26.9	7.6
UK	2.8	7.8	21.1	23.3	19.0	4.3
Total	3.6	6.1	15.0	20.5	15.8	4.7

Number of observations differs across columns, between 8501 (collaborations) and 9013 (co-applied patents).

[a] Co-applied patents are patents applied for by more than one organisation. Patents with external co-inventors are patents listing more than one co-inventor, and with at least two co-inventors employed by different organisations at the time of the patent.

4.3. Geographical proximity and exchange of knowledge among inventors

Another factor promoting the exchange of knowledge may be geographical proximity. We compare the extent to which geographical or organisational proximity (i.e. affiliation to the same organisation) encourages collaboration. PatVal asked inventors to rate from 1 to 5 the importance of four types of interactions in the development of the patented invention: (1) interactions with people in the inventor's organization, and geographically close (who could be reached in less than an hour); (2) interactions with people in the inventor's organization, and geographically distant (more than 1 h distant); (3) interactions with people not in the inventor's organization, and geographically close; (4) interactions with people not in the inventor's organization, and geographically distant.

Fig. 1 shows the importance of the four types of interactions. Organisational proximity is the most important category. Interactions in the same organization are on average more important than interactions with people in other organizations, especially when they are geographically close. Fig. 1 reports the total EU6 data, but we find the same pattern for all six countries individually. Surprisingly, interaction with geographically close individuals in other organizations is the *least* important form of collaboration. This is puzzling given the emphasis in the literature on the importance of geographical proximity for collaboration and knowledge transfer. Geographically localised spillovers may be more important in technological fields featuring small technology-intensive companies organised in clusters. We checked whether geographical proximity ranked differently across technological classes, but the importance of the four types of interactions in the 5 macro- and 30 micro-technological classes of the ISI-INPI-OST classification system does not change. By means regression analysis, Giuri and Mariani (2007) found that being in a technological cluster does not increase the importance of local interactions. Rather, the results of the study suggest that local knowledge interactions are established because of the individual inadequacy to enter wider networks: the higher the scientific content of the research conducted and the inventors' educational background, the wider the research networks. Yet, we cannot rule out that geographical proximity and formation of technological clusters are less important in Europe than other regions of the world (much of literature pertains to the US), but our result is puzzling, nonetheless.

4.4. Sources of knowledge in the invention process

The PatVal survey also asked inventors to rate the following sources of knowledge from 1 (not important) to 5 (very important): competitors, suppliers, customers, other patents, scientific literature, participation in conferences and workshops, university and public research labs. Fig. 2 shows the average assessment of the importance of these sources.

Customers are the most important source of knowledge for invention processes, followed by the patent and scientific literature. The prominent role of customers is consistent with a long-standing view in the literature. The

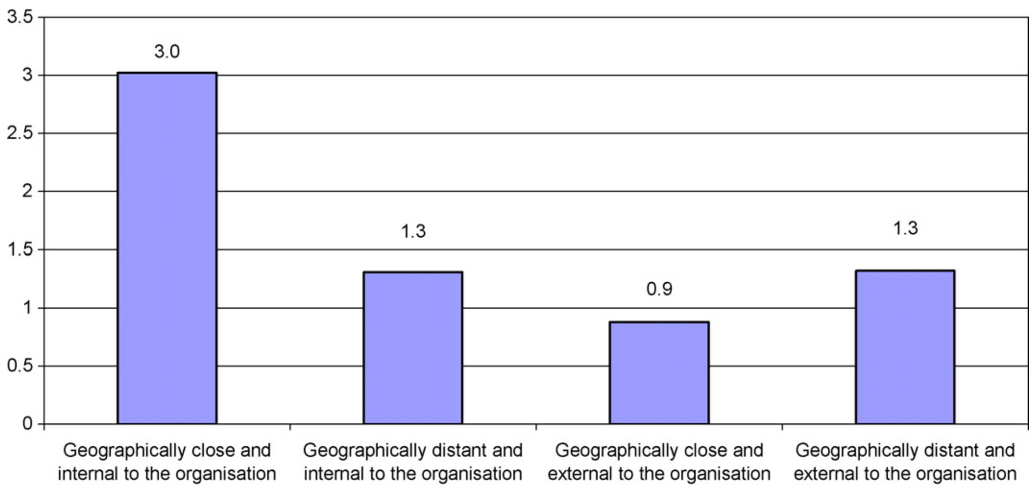

Fig. 1. Importance of geographical and "organisational" proximity of inventors. Scale: 1 (not important) to 5 (very important). Number of observations = 8180.

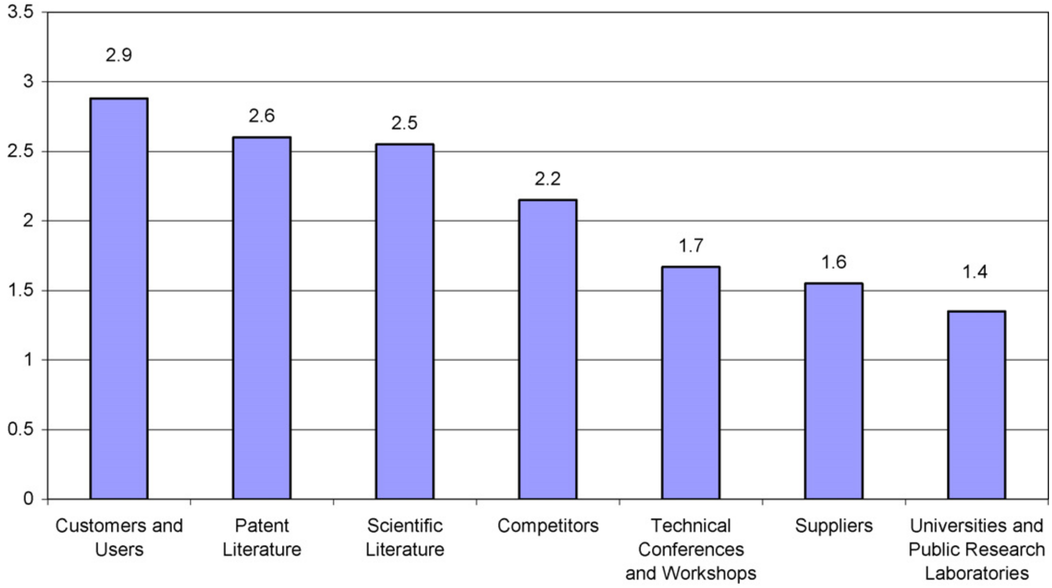

Fig. 2. Average importance of six sources of knowledge used to develop invention (Scale 1–5). Number of observations = 8824.

SAPPHO project developed at SPRU in the 1970s noted that the ability to understand user needs was the most important success factor in the production of innovations (Freeman and Soete, 1997), and this result is likely to apply to inventions as well. Similarly, the importance of a customer-active paradigm has been central in the work of von Hippel (2005). The score of patent literature suggests that the new-patented inventions rely on earlier technological developments, and that the availability of information contained in the patents favours the circulation of knowledge. Moreover, it supports the use of patent indicators. If patents are an important source of knowledge, it makes sense to use patent citations to account for the importance of the patents or the extent of knowledge spillovers from the cited to the citing document. Similarly, the importance of the scientific literature is consistent with the use of patent indicators based on their citations to scientific sources.

It is not surprising that university and public research labs are the least important source of knowledge. In fact, the distance between academic inventions and commercial patented inventions is large in most industries. There can be many steps before the more academic knowledge becomes useful to firms. In this respect, users, customers, suppliers, patents, and more generally industrial sources of knowledge are more important. However, the high score of scientific literature suggests that the more academic knowledge is not unimportant *per se*, but the links with universities or public research labs require effort and investment in establishing relationships. By contrast, scientific literature is readily available provided that one has the required absorptive capacity. In fact, because of a good deal of codification in scientific discourse, the scientific literature provides a relatively good access to relevant knowledge, and there is not much need for the more costly investments of searching for or linking to research labs. Certainly, actual links with a lab provide a good deal of tacit knowledge that cannot be absorbed just from reading the literature, but the effort to link to the research labs may be relatively less important because the scientific literature already supplies a good deal of the relevant information.

5. The use and value of EPO patents

5.1. The use of patents

How do firms use their patents? Why are some patents exploited commercially, while others are licensed out, and yet others are not used? This section uses the PatVal data to answer these questions.

The path between invention and the commercialisation of a new product or a new technology can be long and costly. Moreover, not all inventions and new technologies translate into commercially profitable innovations. Many patents are never exploited, and only a few of them yield economic returns. The decision whether to use a patent and how to use it, depends on a number of factors. For example, the patent owner might not possess the downstream assets to exploit it. Most often, this occurs when the patent owner is a small firm, an individual inventor, or a scientific institution. In these cases, licensing becomes an option (Arora et al., 2001; Rivette and Kline, 2000). Large firms also have unexploited patents (Palomeras, 2003; Rivette and Kline, 2000). Some of them are used strategically to block rivals, to improve the company's bargaining power in cross-licensing agreements, or to avoid being blocked by competitors (Hall and Ziedonis, 2001; Ziedonis, 2004). The literature emphasises the policy implications of the private decision not to use a patent (Scotchmer, 1991; Mazzoleni and Nelson, 1998). The strength of patent protection can increase the propensity to patent and reduce its use. Moreover, the social cost of not using a patent is higher when the patent has a broad scope. In this case, the applicant is less likely to own the full set of heterogeneous assets and competencies that are required to exploit it in its many directions. Yet, patent ownership means that the patent holder can prevent others from using it in any of these ways (e.g. Merges and Nelson, 1990). Nagaoka (2003) reports data on the use of patents by large Japanese firms, and Cohen et al. (2000) show the motivations for patenting of large US companies with formal R&D departments. Both studies show that, apart from protection, licensing, cross-licensing and other strategic factors like "blocking patents" are important reasons for patenting.

These issues need further empirical investigation. For example, the literature on licensing has focused on the industries in which licensing is more frequent, like computers, semiconductors, and chemicals (e.g. Grindley and Teece, 1997; Hall and Ziedonis, 2001, for the semiconductor industry; Cesaroni, 2003; Grindley and Nickerson, 1996, for the chemical industry; Kollmer and Dowling, 2004, for the biopharmaceutical industry), or it has used data aggregated at the level of firms rather than individual patents (Anand and Khanna, 2000; Cohen et al., 2000; Arora and Ceccagnoli, 2006). In general, information on whether the individual patent is used or not, and how it is used is largely unavailable, especially for Europe, and especially at the cross-country and cross-industry scale of our study.

Thus, PatVal provides a unique opportunity to explore these issues. It asked the inventors whether their patents were used for commercial or industrial purposes, or if they were licensed. It also asked them to rate the importance of different motivations for patenting (on a 1–5 scale), including licensing, cross-licensing and strategic reasons like blocking competitors. Appendix 2 describes how we used these responses to define the following six uses of the patents:

(1) *Internal use*: the patent is exploited internally for commercial or industrial purposes, it can be used in a production process or it can be incorporated in a product;
(2) *Licensing*: the patent is not used internally by the applicant, but it is licensed out to another party;
(3) *Cross-licensing*: the patent is licensed to another party in exchange for another patented invention;
(4) *Licensing and use*: the patent is both licensed to another party and used internally by the applicant organisation;
(5) *Blocking patent*: the patent is used neither internally nor for licensing, and was applied for to block competitors;
(6) *Sleeping patents*: the patent is not employed in any of the uses described above. It may still have option value to the holder as an asset protecting a completely different technical approach, but it unfolds no blocking effect w.r.t. competitors.

Table 6 shows that half of EU6 patents (50.5%) are exploited by the applicant organisation for industrial and commercial purposes. About 36% are not used. Of these, about half of them are blocking and the other half

Table 6
Patent use

	Internal use (%)	Licensing (%)	Cross-licensing (%)	Licensing and use (%)	Blocking competitors (unused) (%)	Sleeping patents (unused) (%)	Total (%)
Electrical Engineering	49.2	3.9	6.1	3.6	18.3	18.9	100.0
Instruments	47.5	9.1	4.9	4.3	14.4	19.8	100.0
Chemicals and Pharm	37.9	6.5	2.6	2.5	28.2	22.3	100.0
Process Engineering	54.6	7.4	2.0	4.9	15.4	15.7	100.0
Mechanical Engineering	56.5	5.8	1.8	4.2	17.4	14.3	100.0
Total	50.5	6.4	3.0	4.0	18.7	17.4	100.0

Distribution by technological class. Number of observations = 7711.

Table 7
Patent use

	Internal use (%)	Licensing (%)	Cross-licensing (%)	Licensing and use (%)	Blocking competitors (unused) (%)	Sleeping patents (unused) (%)	Total (%)
Large companies	50.0	3.0	3.0	3.2	21.7	19.1	100.0
Medium sized companies	65.6	5.4	1.2	3.6	13.9	10.3	100.0
Small companies	55.8	15.0	3.9	6.9	9.6	8.8	100.0
Private research institutions	16.7	35.4	0.0	6.2	18.8	22.9	100.0
Public research institutions	21.7	23.2	4.3	5.8	10.9	34.1	100.0
Universities	26.2	22.5	5.0	5.0	13.8	27.5	100.0
Other Govt. institutions	41.7	16.7	0.0	8.3	8.3	25.0	100.0
Other	34.0	17.0	4.3	8.5	12.8	23.4	100.0
Total	50.5	6.2	3.1	3.9	18.8	17.5	100.0

Distribution by inventors' employer. Number of observations = 7556.

are sleeping patents. Finally, 6.4% of the patents are licensed, 4.0% are both licensed and internally used, and 3.0% are used in cross-licensing agreements. Table 6 also shows that there are differences across our five macro-technological classes. However, they are not substantial.

There are more interesting differences across types of applicants. Table 7 shows that large firms use 50% of their patents internally. They trade less than 10% of them, and about 40% are not used. More than half of the unused inventions aim at blocking competitors. The large share of unused patents by large firms is also likely to stem from their lower marginal cost of patenting. Because of their larger scale, they patent more often. For this reason, they create internal divisions specialised in patenting or licensing, or they have specialised managers or assets dedicated to this task. They then exhibit a higher propensity to patent because of the fixed costs involved. As a result, they also patent minor inventions, which are less likely to be used. In fact, this is consistent with the lower share of unused patents by small and medium sized firms in Table 7 (18 and 24%, respectively). Moreover, while medium firms have a higher rate of internal use and partly a higher rate of licensing, small firms have a slightly higher rate of internal use than large firms, and a much higher rate of licensing. The latter is a notable difference. Overall, the small firms license out 26% of their patents and leave 18% unused, which provides a striking contrast to large firms which license out only 10% and leave 40% of their patents unused. This is one of the most remarkable findings of PatVal: firm size and firm type explain a large part of the variation in the extent to which patents are used or licensed. As expected, public or private research organisations and universities license a large fraction of their technologies and do not use them internally (e.g. Mowery et al., 2001). The different licensing behaviour of large and small firms is also confirmed in multivariate analyses. By using the PatVal data Gambardella et al. (2007) find that the most important determinant of patent licensing is firm size. Other factors like patent generality, value, protection, non-core technologies, scientific nature of the patent also affect licensing, but their impact is smaller. They also find that while all the above factors affect the willingness to license a patent, only a few of them, and mainly firm size, affect the probability that licensing actually occurs.

5.2. *Entrepreneurship and patents*

The role of patents as the foundation of new enterprises is conceivably an important one. Patents may be associated with the creation of new firms in technology-based businesses and may thus contribute to more competition and more innovation. Many start-ups in biotechnology, semiconductors, instruments and chemicals use intellectual property as their core asset. Quite often a patent, or possibly a group of patents, represents the key element around which a start-up sets its entire business. As Gans et al. (2002) or Arora and Merges (2004) have noted, when property rights are strong and well enforced, new companies are more likely to start up because they can specialise in developing the technology and selling it to other firms, without incurring the much higher costs and risks of investing in the large scale assets for production and commercialisation. Moreover, patents help them find financing or corporate partners because they provide an independent assessment of the value of the company's competencies.

Recent contributions have studied these issues, mostly in the US. They have analysed the formation of spin-offs that use patents licensed from universities (Shane and Kharuna, 2003), large firms (Klepper, 2001), and venture capitalists (Gompers et al., 2006). Cross-section empirical evidence based on large data samples is

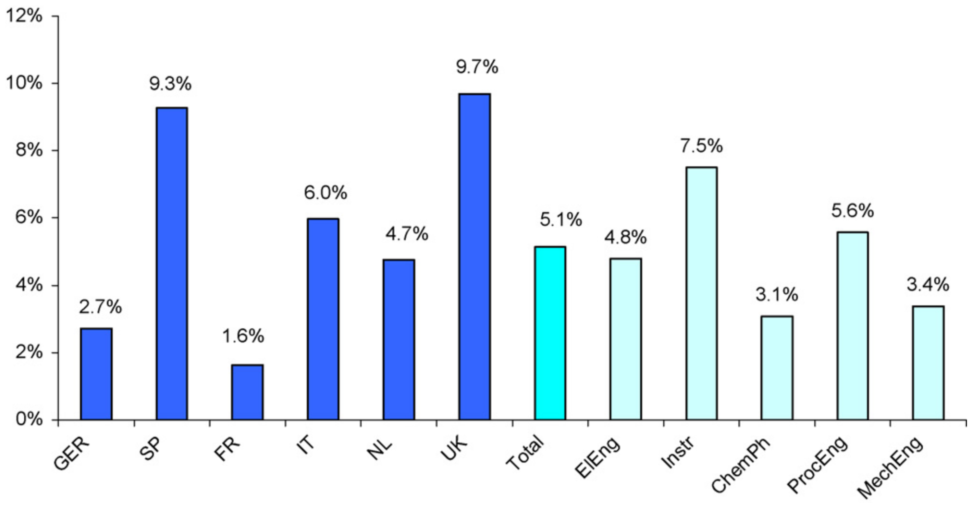

Fig. 3. New firm creation from patented invention. Distribution by country and by technological class. Number of observations = 7391.

limited, however. The evidence for Europe is completely missing.

The PatVal survey asked inventors whether their patents were exploited commercially by starting a new company. Fig. 3 shows the share of patents in the PatVal sample used to start a new firm by country and technological class. For the EU6, 5.1% of the patents give rise to a new firm. This share is larger in the UK (9.7%) and Spain (9.3%). It is smaller in Germany (2.7%) and France (1.6%). As a general remark, the share of UK patents that give rise to a new firm provides additional evidence of the peculiarity of the UK in several aspects of the innovation process. Along with the largest share of new firm formation, the UK has the largest share of licensed patents, of inventors with tertiary education and PhDs, and of patents by universities and research institutions in general. In terms of technological classes, the share of new firms is larger in Instruments (7.5%), followed by Process Engineering (5.6%) and Mechanical Engineering (5.4%). In Chemicals and Pharmaceuticals only 3.1% of the patents are used to create a new firm. One of the more prolific "micro"-technological classes is Medical Technology with 10.5% of patents that gave rise to a new firm.

5.3. *The economic value of patents*

The literature has used indirect measures to estimate the monetary value of patents. They include the number of citations that patents receive after their publication (Trajtenberg, 1990; for a survey see Hall et al., 2001), the renewal fees paid by the patent holders to extend the patent protection (Pakes and Schankerman, 1984; Pakes, 1986; Schankerman and Pakes, 1986), the number of backward citations to other patents and to the non-patent literature (Harhoff et al., 2003a), the number of countries in which the patent is registered for protection, and the incidence of opposition and annulment procedures (Harhoff and Reitzig, 2004). In addition, Lanjouw and Schankerman (2004) constructed a composite indicator of the quality of patents. Only a few studies have used survey-based information on the economic value of patents, but they are limited to specific countries (see, for German and US patents, Harhoff et al., 1999, 2003a, 2003b; Scherer and Harhoff, 2000).

PatVal asked inventors to produce their best estimate of the value of their patented inventions. More precisely, the inventors were asked to estimate the minimum price at which the owner of the patent, whether the firm, other organisations, or the inventor himself, would have sold the patent rights on the day on which the patent was granted. To improve the accuracy of this estimate we asked the inventor to assume that at the time of this counterfactual sale, he would have had all the information available at the moment in which he responded to the questionnaire.[12]

[12] The questionnaire was submitted in 2003–2004, which is 6–7 years after the application year of the latest patents in the survey. This is a sufficient time span for a good deal of the information about the use and value of the patents to become available. As noted in Section 2, the inventors may not be the most informed respondents about the value of patents. See our earlier discussion, and Appendix 3 which describes the test that we performed to assess this potential bias.

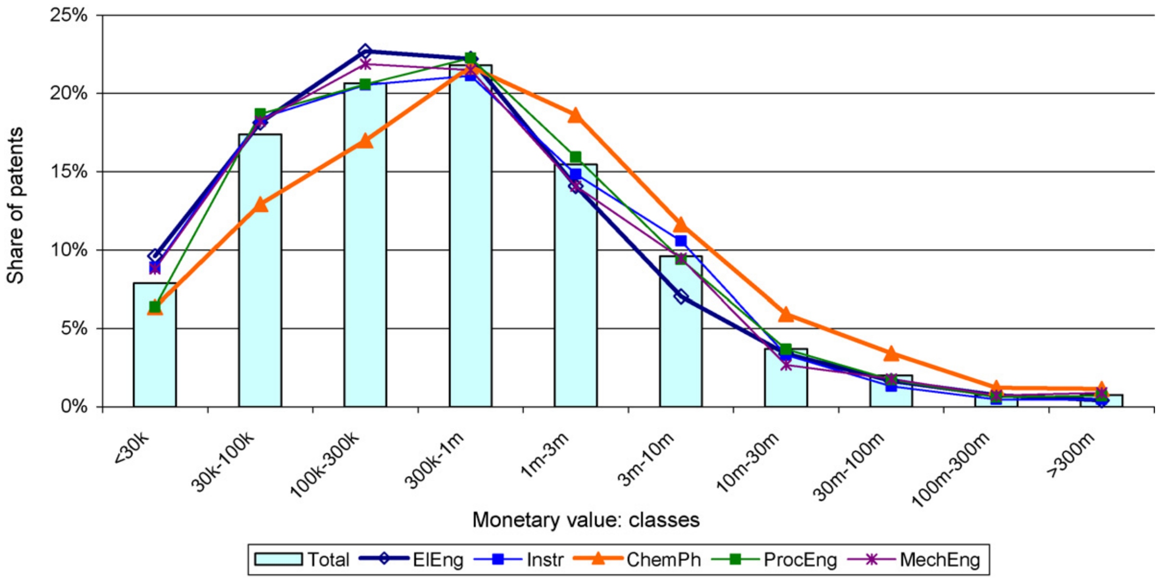

Fig. 4. The value of European patents across macro-technological classes. Number of observations = 7752.

Fig. 4 shows the distribution of the value of the PatVal patents by technological class. The questionnaire asked inventors to rank the present value of their patents in 1 of 10 value classes, ranging from less than 30,000 Euros to more than 300 million Euros.[13] Our results confirm the skewness of the distribution of patent values (Harhoff et al., 1999, 2003b; Scherer and Harhoff, 2000). Only 7.2% of the patents in our sample are worth more than 10 million Euros, and 16.8% have a value higher than 3 million Euros. A share of 15.4% has a value between 1 and 3 million Euros. The largest share of patents falls in the left-hand of the distribution. About 68% of all our patents produce less than 1 million Euros, and about 8% have a value lower than 30,000 Euros.[14] We note that our intervals in Fig. 4 were constructed to obtain a logarithm scale of the variable, i.e. the difference between the logs of the two boundaries of any interval (rather than their absolute values) is roughly equal. Thus, Fig. 4 shows the distribution of the log of the patent values. Since the log of a variable is more skewed than the variable itself, the actual distribution of patent values is even more skewed than the one in Fig. 4.

There are some slight differences in the value of the patents across technological classes. For example, inventions that are worth more than 10 million Euros are more frequent in Chemicals and Pharmaceuticals (11.7%) compared to all the other sectors and to the overall sample (7.2%). Correspondingly, only 58% of Chemical and Pharmaceutical patents generate less than 1 million Euros, while the same share for Electrical Engineering, Instruments, Process Engineering and Mechanical Engineering is about 70%. This confirms that patents are more valuable in chemicals and pharmaceuticals compared to mechanical and electronic technologies.

6. Conclusions

Apart from a few patent surveys with limited European coverage and mostly biased towards large companies, the managerial and economic literature has suffered from the limited availability of detailed and direct data on the characteristics of invention processes and the economic value of its output. The PatVal survey was designed to close this gap. Compared to previous surveys on patents, PatVal has a much broader coverage in terms of European countries, and in terms of types and size of the applicant organisations.

The paper first described the characteristics of European inventors. It confirms the extremely limited participation of women in invention activities in Europe:

[13] Clearly, patent values are affected by our over-sampling of important patents. Yet, as noted, our correction produced very small differences because the over-sampling regards only a small share of patents at the right tail of the distribution.

[14] We cannot rule out that the inventors have over-estimated the values at the very left tail of the distribution. This is because it may be psychologically difficult for a respondent to declare that his innovation is worth nothing, or a very small amount. We address this problem in Appendix 3 of this paper.

2.8% of the total PatVal sample. In terms of educational background, about three-quarters of the European inventors in the PatVal dataset have a university degree. Only one quarter have a PhD, with Italy lagging behind in both categories. Moreover, the European inventors are *not* very mobile across jobs. More than three-quarters of the PatVal inventors never moved from their job in a window of about 10 years after they produced the patent for which they were interviewed. The UK exhibits the largest share of inventors (almost 40%) who changed job at least once during their career.

PatVal offers new information about the motivation of inventors to invent. Typically, inventors consider monetary rewards and career advances less important than personal and social rewards, like personal satisfaction, prestige, reputation, and contribution to the performance of the organisation. As far as the invention process is concerned, only one-third of the patents are developed by individual inventors, suggesting that most inventions are the outcome of a team activity. However, the vast majority of co-inventors belong to the same organisation. Only 15.0% of the EU6 patents are produced by teams of inventors affiliated with different organisations. At the organisational level, 20.0% of patents are developed in collaboration with other institutions. About three-quarters of these collaborations are formalised through specific contracts, as opposed to being established on an informal, non-contractual basis. Finally, by comparing the share of co-applied patents with the share of collaborative patents, a large fraction of collaborations does not result in joint patent applications. Since the latter (co-patenting by multiple applicants) is the only information on collaboration in the patent document, the available information in the patent files severely under-estimates the actual extent of collaboration in the development of patents. We therefore signal caution in interpreting co-application patterns as a “true” measure of collaboration.

Customers are the most important source of knowledge for the patented invention, followed by other patents and the scientific literature. Competitors, participation in conferences and workshops and suppliers rank next. Surprisingly, university and non-university research laboratories are the least important source in all of our EU6 countries. We also found that while “organisational proximity” (i.e. being in the same organisation) encourages interactions of the inventors with other sources of knowledge, geographical proximity does not influence the probability of collaboration when the researchers belong to different organisations. Geographical proximity is not important either for the technologies that are known for being characterised by geographical clustering. This might suggest that, when examined using a large-scale sample of patents and inventions, the extent of localised geographical interactions for invention is more limited than emphasised by the literature. In addition, it may be particularly unimportant in Europe.

The survey also produced information about the use and non-use of patents. We find that about one-third of the patents are not used for specific economic or commercial activities (whether exploited internally or licensed). Of these about half are dormant, while the others are blocking patents. Moreover, only 13.4% of patents are licensed. The most interesting difference is between large and small firms. Small firms license about 26% of their patents and leave only 18% of patents unused, while the respective percentages for larger firms are 10 and 40%. Since large firms presumably have lower patenting costs, they probably patent minor inventions as well, which are less likely to be used. For the smaller firms, patenting costs are important, and they tend to patent only inventions for which they can obtain some returns. As an alternative explanation, it might be possible for larger firms to derive greater strategic value from marginal patents, e.g., by using them to deter entry. Moreover, the higher share of licensing by small firms is consistent with a growing literature suggesting that firms with limited downstream assets are more likely to exploit their inventions through technology trade. Finally, we confirm that the distribution of patent values is highly skewed, and only a few patents yield large returns.

Acknowledgements

We are grateful to Angela Hullmann, Viola Peters, Hugh Richardson at the European Commission and Manuel Desantes at the European Patent Office for their help. We also thank Serena Giovannoni, Manuela Gussoni and Luisa Martolini for excellent research assistance. We acknowledge financial support of the European Commission (Contract HPV2-CT-2001-00013). Economic support was also provided by the Italian Ministry of Education (Miur, 2003–2005), the Italian CNR (Promozione Ricerca, 2004), Bocconi University (RdB project, II tranche, 2005), and the CNR—ESF Project “Science and Technology in Large and Small Firms”.

Appendix A. The PatVal-EU Survey

A.1. The questionnaire

The PatVal questionnaire focused on the topics described in Section 2, and it was divided into six sections: (A) Inventor's Personal Information; (B) Inventor's Education; (C) Inventor's Employment and Mobility; (D) The Invention Process; (E) Inventor's Rewards; (F) Value of the Patent. The questionnaire is downloadable at http://www.lem.sssup.it/projects/resfiles/Patval_ANNEX_I_Questionnaire.pdf.

A.2. The sampling procedure

At the time of the survey our six countries covered 42.2% of the total EPO patents by country of first inventor, and 88.0% of the EPO patents with country of first inventor being one of the EU-15 (source: EPO EPASYS database). Patents were assigned to countries according to the location of the first inventor in the inventors' list. The share of questionnaires submitted to inventors in each country depended on the country share of patents in the whole population: Germany 49.7%, France 19.5%, the UK 15.0%, Italy 8.5%, the Netherlands 6.2% and Spain 1.07%. We under-sampled the share of German and French patents, and over-sampled the patents invented in the other countries in order to have sufficiently large samples for all of them. Since our goal was to receive about 10,000, we set the following target responses by country: 3500 for Germany, 1750 for France, 1750 for the UK, 1250 for Italy, 1250 for the Netherlands, and 500 for Spain. The response rate in the pilot surveys helped to decide the number of questionnaires to send to the inventors in each country to obtain returns close to the target. To improve the response rate, the EPO and the European Commission provided us with a cover letter for the questionnaire.

Our population is composed of all the EPO granted patents with a priority date between 1993 and 1997. This is because, if we sampled very "old" patents, it would have been difficult to track down the inventors or to find someone who remembered enough about the invention process. By contrast, very "recent" patents might not carry enough information about their value and use.

In the sampling procedure we took into account that the distribution of patent values is highly skewed. We therefore over-sampled the "important" patents, which we defined as patents that were opposed or that received at least one citation. Without such an over-sampling we would probably end up with very few patents in the upper tail of the distribution of patent values. In the end we selected a stratified sample of 27,531 EPO patents that included all the opposed or cited patents in the 1993–1997 patent population, and a random sample of the uncited and unopposed patents. As noted in the text, the over-sampling procedure produced about 15% additional observations for the opposed or cited patents at an aggregate EU6 level (43.2%) compared to the initial population (28.5%). The full PatVal Final Report (2005) also reports individual country shares of opposed or cited patents in the population of patents with a priority date of 1993–1997 and in the PatVal sample.

A potential problem may arise with inventors of more than one EPO patent. If they had to fill out multiple questionnaires, they could decide to drop them all, producing a potential bias against the more prolific inventors. To avoid this problem, we sent a maximum of five questionnaires per inventor even if he/she was listed in more than five patents in our sample (very few cases). We also asked multiple patent inventors to fill out the complete questionnaire for only one patent, and to skip Section A (and possibly B and C) in the other patents. Whenever possible, we asked the co-inventors to fill out some of these patents, and we made a particular effort to convince multiple patent inventors to respond to the survey.

A.3. Pilot surveys

We performed three pilot tests before running the full-scale survey. The aims were to choose the best method for submitting the questionnaire in each country (mail, telephone, internet) and to check whether the respondents understood the questions clearly. In the final pilot test we reproduced the conditions under which the full-scale survey would be performed.

A.4. Searching for the inventors

A critical task of the survey was to find the recent addresses and telephone numbers of the inventors listed in the patents. We faced two problems. First, we needed the inventors' telephone number to check for their address and to contact them for the telephone interviews. Second, many addresses of the "mobile" inventors at the time of the survey had changed with respect to those listed in the patent in 1993–1997. During the pilot tests we designed a common set of rules to search for the inventors' addresses and telephone numbers in the six countries.

We started by looking for the address of the first inventor listed in the patent in telephone directories of each country involved. We obtained 64% "exact-matches", i.e. the name–surname and address listed in the patent was the same as in the directories. These inventors could thus be easily found and approached.[15]

[15] Some inventors listed the address of the organisation for which they worked. We then contacted the company and asked to interview the inventor. They were a few cases.

However, we also had to find some non-exact matches to avoid biases against the mobile inventors. We searched for two types of "non-exact matches": inventors *with* and *without* EPO patents after 1997. In the former case, if the address in the later patent matched the one that we found in the phone directory, we contacted the inventor before submitting the questionnaire. Clearly, this was not sufficient as it might produce a bias towards the mobile and productive inventors who produced later EPO patents. To trace inventors who did not have other EPO patents we performed the following search: (1) we checked whether the same name–surname was in the city at a different address. In this case, we called the person. If there were up to 2–3 individuals with the same name–surname, we called all of them to find out who was our inventor; (2) we searched for the same name–surname in the wider regional area and at the national level. Again, we called the person to find out whether he was the inventor (up to 2–3 people); (3) we used the address of the second or third inventors (if there were any) in our 1993–1997 survey sample of patents, and we asked them for information about the first inventor (including his address). Only if we could not find the first inventor, did we ask the second or third inventor to respond to the questionnaire; (4) we finally searched for the inventors in the US patent data, and we surfed on the internet for useful information. To achieve overall uniformity of the procedure we issued "Guidelines to search for inventors" that were distributed to all team members.

The UK showed some differences. First, exact-matches were only 18%, compared to 65% in France, 86% in Germany, 62% in Italy, 66% in the Netherlands and 89% in Spain. This is because in the UK people can choose whether or not they want to be listed in the telephone directory, whereas in the other countries they are listed without permission being asked. Thus, to obtain a number of responses comparable to the other countries, in the UK we had to send out a much larger number of questionnaires. They were sent to the address of the inventor listed in the patent. The returned questionnaires were clearly a subset of the inventors whose address matched that in the patent. We then performed an additional search following the steps above to avoid biases against the mobile inventors. In the UK, we had the additional problem that directories do not report the full first name of the customers, making Steps 1, 2, and in part 3 above hard to perform, with a large number of telephone calls needed to find the right person.[16]

[16] See the PatVal Final Report (2005) for response rates, and several other details concerning the search for inventors, or questionnaire submissions.

Our final sample of 9017 patents includes 7% responses from inventors whose exact address only matched a later EPO patent (after 1997), and 5% inventors without a later EPO patent, whose address was found with this procedure.[17] The remaining 88% responses are exact matches. Because the average of exact matches is 64%, our full-scale dataset under-represents the 36% non-exact matches. Also, we have no way to figure out whether the proportion between inventors with and without later EPO patents is really 7–5. Thus, we have to be careful about this potential bias in our data. However, the fairly high rate of exact matches (64% on average, but even above 80% for Germany or Spain) suggests that in Europe the mobility of inventors is not pronounced. Hence, the extent of this potential bias may not be dramatic. The problem may be more serious for the UK.

A.5. The full-scale survey

In order to maximize the response rate, each team chose the methodology to apply to his country during the full-scale survey, and all the teams employed a "recall strategy". Details of the specific country strategies for the interviews are in the PatVal-EU Report (2005). The full-scale survey started in May 2003. The last country to finish the interviews was France in April 2004.[18]

Appendix B. Definition of the six uses of the patents

The definition of the "uses" of patents takes up five questions of the PatVal questionnaire. The first two questions ask (answers Y/N)[19]:

(Q1) Has the patent been exploited commercially?
(Q2) Has it been licensed to an independent party?The other three questions ask about the motivations to patent (answers 1–5; 1 = not important; 5 = very important):

[17] The differences across countries in the two percentages are small.
[18] In each country a professional poll-company conducted one or more steps of the survey. Only the Dutch team performed all the tasks internally, while in France the survey was conducted by the Ministère de la Jeunesse, de l'Éducation Nationale et de la Recherche, and it started in September, 2003.
[19] Both Q1 and Q2 allowed for a third response, viz. "No, but still investigating the possibility". For this purpose, we lumped it together with "No".

(Q3) Has *licensing for revenue purposes* been an important motivation for this patent?
(Q4) Has *cross-licensing* been an important motivation for this patent?
(Q5) Has the goal of *blocking competitors* been an important motivation for this patent?

We then defined:

Internal use (*only*) = (Y, N)
Licensing (*only*) = {(N, Y) ∪ [(Y, Y) ∩ (Q3 = 4–5)]} ∩ (Q4 = 1–3)
License and internal use = (Y, Y) ∩ (Q3 = 1–3) ∩ (Q4 = 1–3)
Cross-licensing = [(N, Y) ∪ (Y, Y)] ∩ (Q4 = 4–5)
Blocking patent = (N, N) ∩ (Q5 = 4–5)
Sleeping patent = (N, N) ∩ (Q5 = 1–3)

The definition of the licensed-only patents takes into account the possibility that the respondents have interpreted the expression "exploited commercially" in Q1 as including either licensing or internal exploitation. Thus, apart from patents in which the respondent answered "No" to Q1 and "Yes" to Q2, our licensed-only patents include patents in which the respondents answered "Yes" to both Q1 and Q2, provided that they gave a high score (4 or 5) to licensing for revenue purposes as a motivation for patenting. Cross-licensing are licensed patents (i.e. Q2 = Yes) with a high score (4–5) to cross-licensing as a motivation.

Appendix C. Check for validity of responses: the French test

We performed a statistical test to check the potential bias in the inventors' responses. The opportunity arose from the French survey which was conducted by the Ministère de la Jeunesse, de l'Éducation Nationale et de la Recherche in Paris. The Statistical Department of the Ministry had extensive databases and information about applicant organisations that made it easier to contact them. As a result, unlike the other countries, in which all the questions were asked to the inventors, in the French case the questions about costs of the research, source of funding, use of patents, and value of the patent families were asked to the patent applicant and not to inventors. The question about the monetary value of the individual patent was asked to both inventors and companies. All the other questions were asked only to inventors. We then used for our test the question on the value of the single patent, which was asked to both. For this question the French questionnaire had 354 patents with valid answers by both inventor and applicant organisation.[20]

We first found that the distributions of the value classes provided by the inventors and the managers overlap to a great extent. Moreover, a two-tail t-test did not reject the hypothesis that the two means are different for a p-value <10%. Pride or other factors may induce inventors to boost the results of their work, and hence to over-estimate the value of their patents. If so, it is reasonable to employ a one tail t-test of the null hypothesis of no difference between the two means against the alternative that the mean response of the inventors is higher than that of the managers. In this case the null hypothesis is rejected at $p < 5\%$, suggesting that inventors over-estimate the value of their patents compared to managers. However, such an over-estimation is small. The PatVal-EU Report (2005) describes the details of these and other tests that we performed.

We also compared the different responses between inventors and managers in small and large firms. As noted earlier, inventors in large companies may be less informed about the value of their patents because of the greater organizational distance and more intensive specialisation of tasks. As a result, the gap in response should be wider in these firms. Among our 354 French patents we distinguished between the patents applied for by the large firms (more than 250 employees), small-medium firms (less than 250 employees), and universities and other research organisations. We found that a slight over-estimation of the inventor's assessment of the value of their patents compared to the managers is produced by inventors in the large firms. The difference is smaller for small-medium firms and inventors in academia and other non-profit research institutions. See the PatVal-EU Report (2005) for detail.

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[20] In France, 587 patents had responses from both inventor and applicant organisation. However, for 233 of them there was no response to the value question by the inventor, the applicant or both, leading to 354 patents with valid answers from both.

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